Appendix H: Climate impacts and adaptation actions for mule deer

Figure H.1. Mule deer.

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the mule deer (*Odocoileus hemionus*).

The mule deer is a widely distributed herbivore which is relatively sensitive to anthropogenic barriers to connectivity.[2] In the transboundary region of Washington and British Columbia, the mule deer utilizes a variety of native habitats, and exhibits relatively high habitat connectivity.[2] Barriers to mule deer movement are presented by development, roads and traffic, and the presence of people and domestic animals,[2] with significant barriers present along major highways (Appendix H.1).[2]

Future climate change may present additional challenges and needs for mule deer habitat connectivity.[3-4] First, climate change may impact mule deer core habitat and dispersal corridors in ways that may make them more or less permeable to movement. Second, existing mule deer core habitat and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in mule deer distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for mule deer habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on mule deer habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary mule deer habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence mule deer habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix H.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The mule deer conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to mule deer habitat connectivity.

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[i] This report is Appendix H of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on mule deer connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

Key impacts on transboundary mule deer habitat connectivity identified via this approach include changes in areas of mule deer climatic suitability, changes in water availability, and changes in disturbance regimes.

Changes in areas of climatic suitability

Climate change may impact mule deer habitat connectivity by changing the extent and location of areas of climatic suitability for mule deer; this may render some existing core habitat areas and corridors unsuitable for mule deer, and/or create new areas of suitability. Climatic niche models provide estimates of species' current and projected future areas of climate suitability, and are available for the mule deer for the 2080s based on two CMIP3 Global Circulation Models (GCMs) (CGCM3.1(T47) and UKMO-HadCM3[ii]) under the A2 (high) carbon emissions scenario[iii] (Appendix H.3).

For both climate models, projections for the 2080s show nearly all currently suitable habitat remaining climatically suitable for mule deer. The exception to this is a decline in climatic suitability in the Purcell Mountains; this decline is much more widespread for the UKMO-HadCM3 model. Climatic suitability is projected to improve in high elevations. Changes in climatic suitability may thus be expected to have a neutral or positive affect on mule deer habitat connectivity.

Changes in water availability

Projected declines in summer precipitation and increases in summer water deficit (Appendix H.6: Total Summer Precipitation, June-August; Water Deficit, July-September) could reduce the amount of water available in ponds and streams. Changes in the distribution and abundance of these water resources could affect movement patterns and make movements through dry locations more challenging for mule deer during the summer. In addition, decreasing summer soil moisture (Appendix H.6; Soil Moisture, July-September) could reduce the amount of available browse, which could further reduce the habitat quality of mule deer corridors through dry regions.

[ii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

Changes in disturbance regimes

Climate change may affect mule deer habitat connectivity through increasing frequency and severity of summer drought (Appendix H.6: Dry Spell Duration; Water Deficit, July-September), increasing risk of wildfires (Appendix H.6: Days with High Fire Risk), and changes in pest and pathogen dynamics. Drier conditions could reduce the amount and/or quality of moist habitats and forests. A longer fire season and increase in area burned could also affect forest.[11] Moisture stress and fire can increase tree mortality and bark beetle outbreaks, which can further increase the chances of large, high-intensity fires (Appendix H.5: Probability of Mountain Pine Beetle Survival). Such disturbance events could affect mule deer connectivity by reducing the amount and/or quality of available core habitat and movement corridors.

Adaptation responses

After identifying potential climate impacts on mule deer habitat connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix H.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on mule deer habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in mule deer distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on mule deer habitat connectivity

Actions to address the potential for climate change to impact connectivity through changes in water availability include:

- Planning corridors so that water resources, such as streams or wetlands, are available; these may become increasingly important as the climate changes, particularly in dry, lowlands valleys such as the Okanagan Valley.
- Maintaining wetlands. For example, if frost seal does not occur often enough to maintain spring wetlands, consider artificially irrigating key wetlands.

Actions to address the potential for climate change to impact connectivity through more frequent and severe wildfires include:

- Using prescribed burns and thinning to reduce the risk of catastrophic wildfires and pest outbreaks that could negatively impact mule deer core habitat areas and corridors. Consider engaging traditional ecological knowledge to help guide implementation, referencing the forest and grazing practices of First Nations and tribes to identify traditional strategies for managing fire risk and other potential climate impacts. In developed areas, implementing a new prescribed burn program would require careful evaluation of associated risks and benefits.
- Incorporating projections and observations of changes in the length of the snow season, evapotranspiration, soil moisture deficits, and the timing of precipitation to inform the timing of fire prevention techniques as conditions change, in order to maximize their safety and effectiveness.

Enhancing connectivity to facilitate range shifts

Actions that may help the mule deer adjust its geographic distribution to track shifts in its areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors,[7] Appendix H.1), to ensure that mule deer have the ability to disperse into moister, higher elevation habitats as the climate warms.
- Focusing habitat retention efforts on riparian habitats, which span climatic gradients and are frequently used by mule deer as movement corridors.

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Highways, (e.g., Highway 97, Highway 3A, Highway 3, and US Interstate 90), which present dispersal barriers for mule deer. For example, Highway 3 cuts east-west through E.C. Manning Provincial Park and may create a dispersal barrier for south-north movement through the North Cascades; if there is evidence that the road creates a barrier, it could be a candidate for a crossing.
- Riparian areas, which currently provide important mule deer habitat and dispersal corridors (particularly through dry, low elevation valley) and also span climatic gradients, facilitating dispersal into cooler habitats.

Policy considerations

Referrals response

Actions for addressing climate impacts on mule deer habitat connectivity through First Nations and tribal referrals response processes include:

- For highway expansion projects (e.g., the Osoyoos project), encouraging the use of highway design techniques that preserve connectivity (e.g., overpasses, open span bridges, and culverts), both on and off First Nation and tribal lands.
- Encouraging the incorporation of wildlife-friendly fencing into permitting and planning processes. Promoting the use of such designs may help facilitate mule deer movement.

Land and water use planning, management, and zoning

Actions for addressing climate impacts on mule deer habitat connectivity though land and water use planning, management, and zoning include:

- Coordinating with transportation planning agencies to minimize road impacts to mule deer habitat connectivity, and ensure that new roads do not negatively impact important mule deer corridors under climate change.
- Using large parcel zoning to maintain contiguity of natural areas within tribal and First Nation lands. Outside of tribal and First Nation lands, work with private landowners and with environmental policy to maintain contiguous swaths of suitable land that will facilitate connectivity.
- Securing water rights to maintain moisture in riparian areas and wetlands that provide habitat and movement corridors through dry, low elevation valleys.

- Reviewing and implementing existing guidance and plans relating to mule deer habitat management. Evaluating existing recommendations for opportunities to address climate impacts.
- Coordinating stewardship and management activities with provincial and local governments, NGOs, tribes and First Nations, and especially with private landowners.

Hunting regulations

Actions for addressing climate impacts on mule deer connectivity through hunting regulations include:

- Considering timing tribal and First Nation hunting seasons around key dispersal periods and/or lowering take limits to reduce pressure on mule deer populations.

Research needs

Future research that could help inform mule deer connectivity conservation under climate change includes:

- Developing transboundary fire models. These models could improve assessment of potential impacts, and direct fire management activities toward core habitat areas and corridors identified as being at high fire risk.
- Developing transboundary pest models (e.g., mountain pine beetle, spruce budworm, and western pine beetle). These models could improve assessment of potential impacts, and direct forest health activities toward core habitat areas and corridors identified as being at high risk of insect or pathogen outbreaks.
- Developing fine-scaled, transboundary riparian models. These could help identify high quality riparian corridors that could facilitate movement despite general regional warming.

References

1. Krosby, M., Michalak, J., Robbins, T.O., Morgan, H., Norheim, R., Mauger, G., and T. Murdock. 2016. The Washington-British Columbia Transboundary Climate-Connectivity Project: Identifying climate impacts and adaptation actions for wildlife habitat connectivity in the transboundary region of Washington and British Columbia. Climate Impacts Group, University of Washington.
2. Washington Wildlife Habitat Connectivity Working Group. 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA. www.waconnected.org.
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4. Cross, M. S., Hilty, J. A., Tabor, G. M., Lawler, J. J., Graumlich, L. J., and J. Berger. 2012. From connect-the-dots to dynamic networks: Maintaining and restoring connectivity as a strategy to address climate change impacts on wildlife. *In*: J. Brodie, E. Post, D. Doak, eds. *Conserving wildlife populations in a changing climate*. Chicago University Press.
5. Heller, N. E., and E. S. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142**:**14–32.
6. Cross, M.S., et al. 2012. The Adaptation for Conservation Targets (ACT) framework: a tool for incorporating climate change into natural resource management. *Environmental Management* 50:341–351.

7. Washington Wildlife Habitat Connectivity Working Group. 2011. Washington Connected Landscapes Project: Climate gradient corridors report. Washington Departments of Fish and Wildlife, and Transportation. Olympia, WA. www.waconnected.org.

8. Integrated Scenarios of the Future Northwest Environment. http://climate.nkn.uidaho.edu/IntegratedScenarios

9. Pacific Climate Impacts Consortium (PCIC), Regional Analysis Tool. 2014. https://www.pacificclimate.org/analysis-tools/regional-analysis-tool

10. Pacific Northwest Climate Change Vulnerability Assessment (PNWCCVA). http://www.climatevulnerability.org/

11. McKenzie, D., Gedalof, Z., and D.L. Peterson, and P. Mote. 2004. Climatic change, wildfire, and conservation. *Conservation Biology* 18:890-902.

Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[iv]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[v] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

[iv] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[v] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices H.1-6

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For mule deer, these materials include:

Appendix H.1. Habitat connectivity models
Appendix H.2. Conceptual model of habitat connectivity
Appendix H.3. Climatic niche models
Appendix H.4. Projected changes in vegetation communities
Appendix H.5. Projected changes in probability of mountain pine beetle survival
Appendix H.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[2,7] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[8] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[10]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. H.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

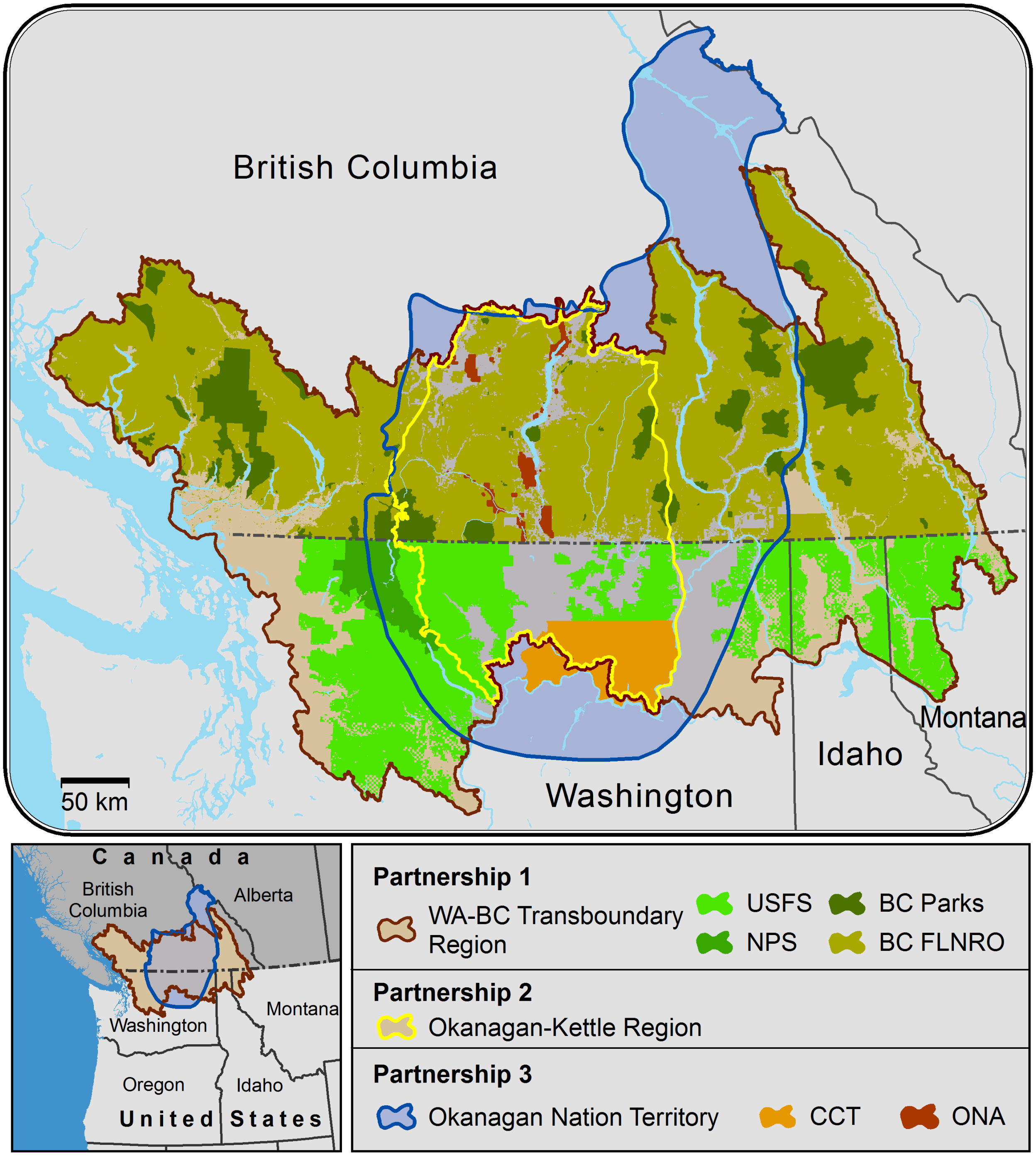


Figure H.2. Project partners and assessment areas.

Appendix H.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vi] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

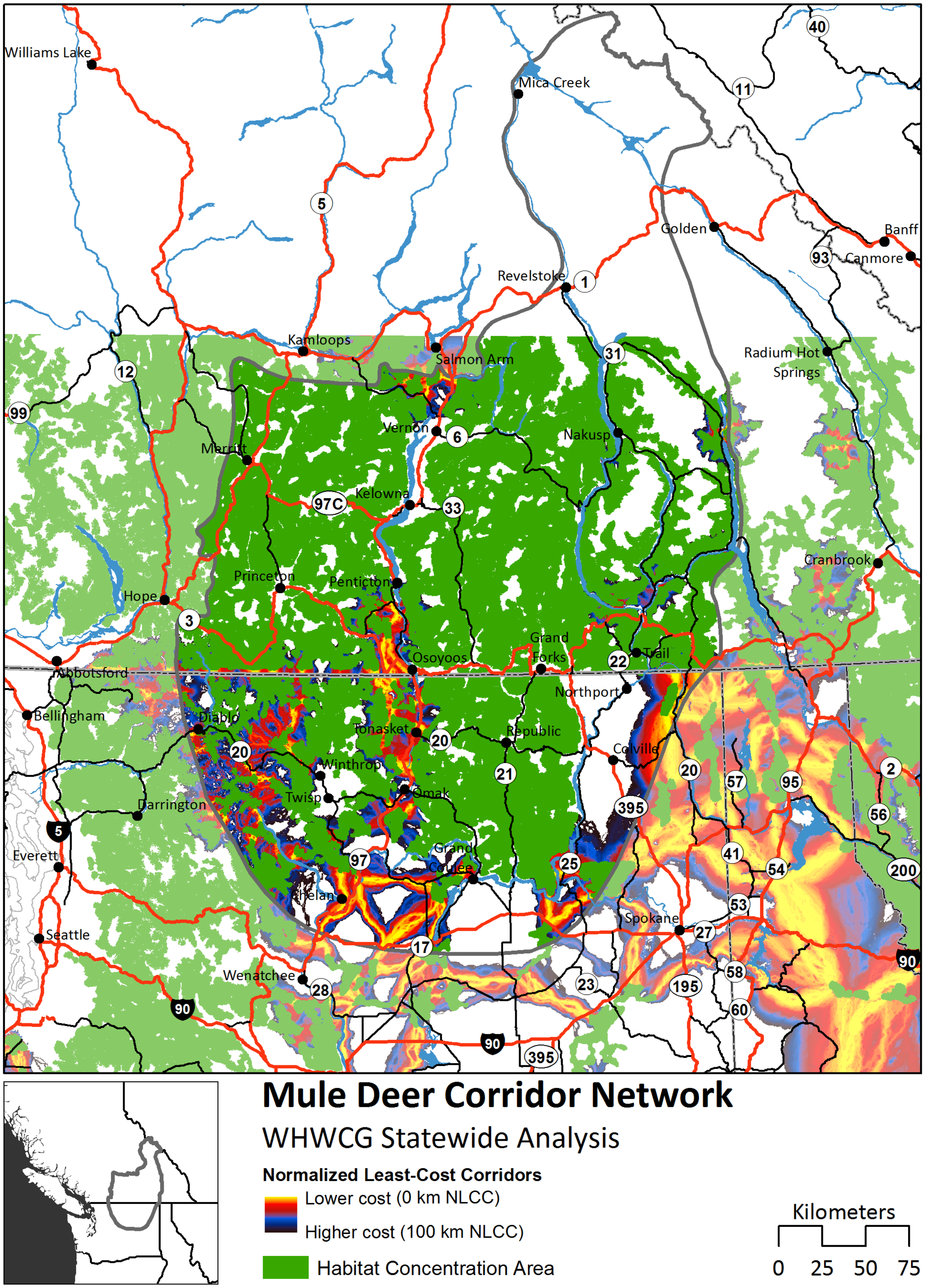
a) **WHCWG Statewide Analysis: Mule Deer Corridor Network.[2]** This map shows Habitat Concentration Areas (HCAs, green polygons), which are large, contiguous areas featuring little resistance to species movement; and corridors (glowing yellow areas) connecting HCAs, modeled using least cost corridor analysis. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).[7]** This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 °C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vi] For detailed methodology and data layers see http://www.waconnected.org.

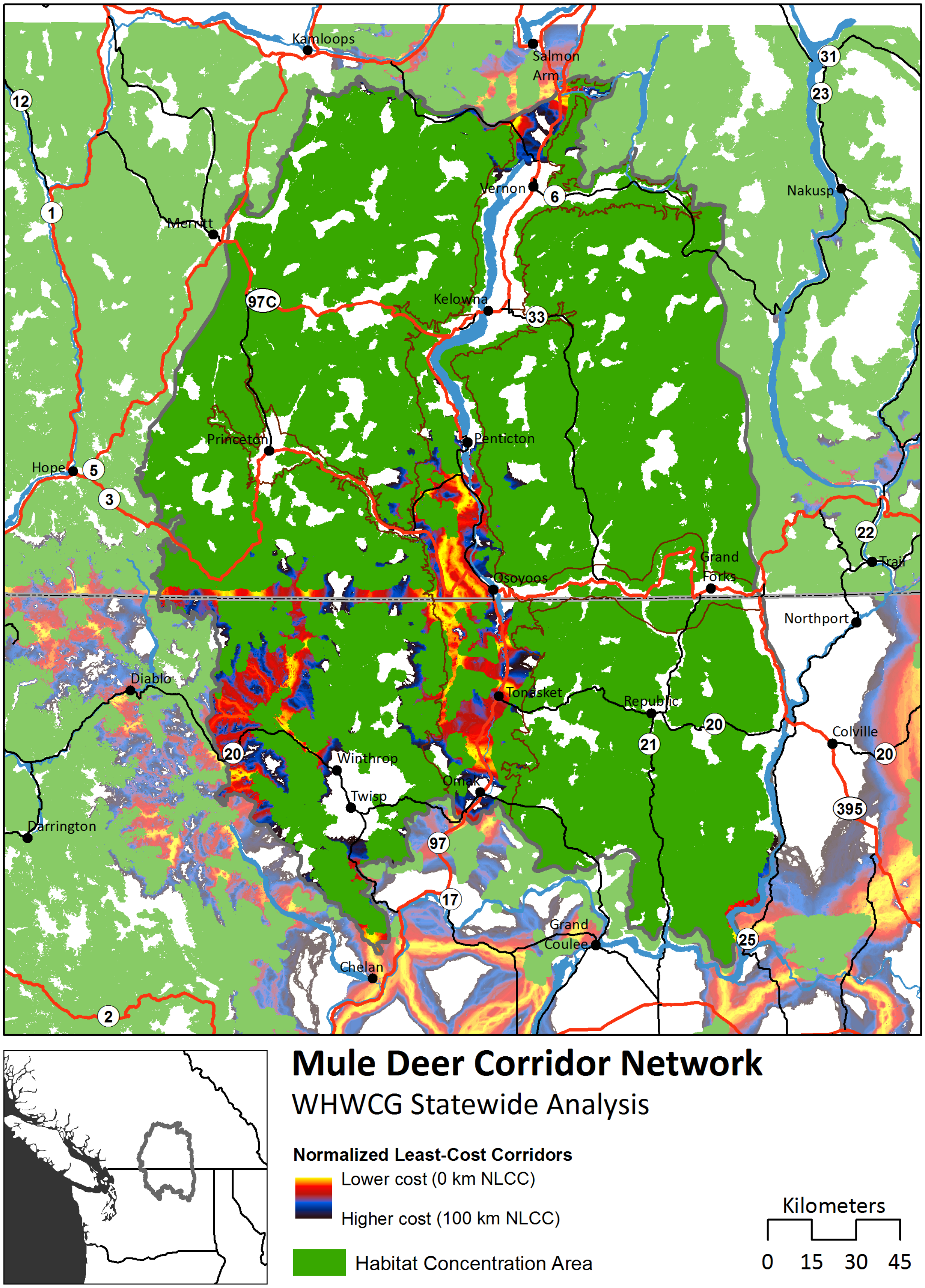
Appendix H.1a. WHCWG Statewide Analysis: Mule Deer Corridor Model

i) Extent: Okanagan Nation Territory



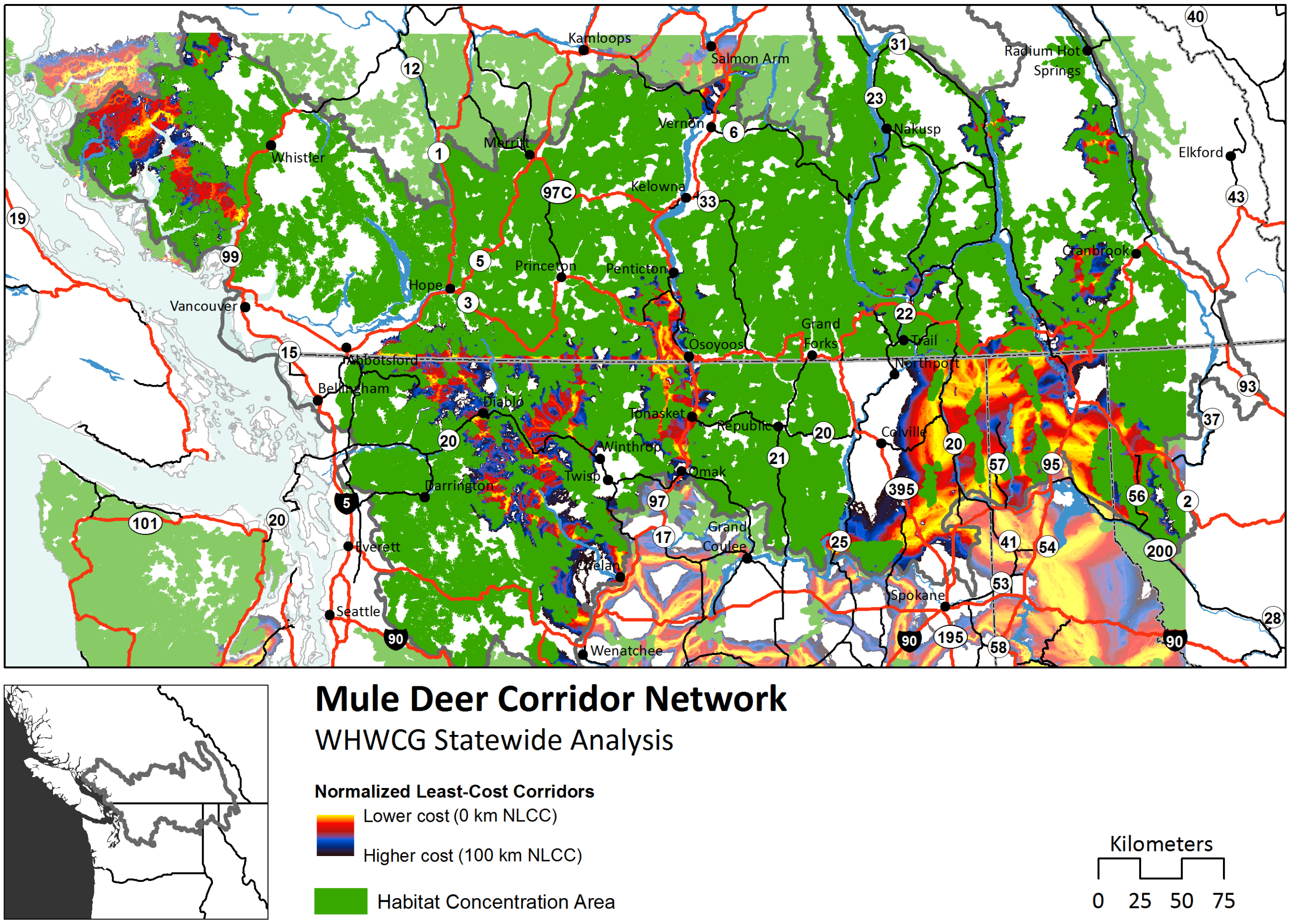
Appendix H.1a. WHCWG Statewide Analysis: Mule Deer Corridor Model

ii) Extent: Okanagan-Kettle Region



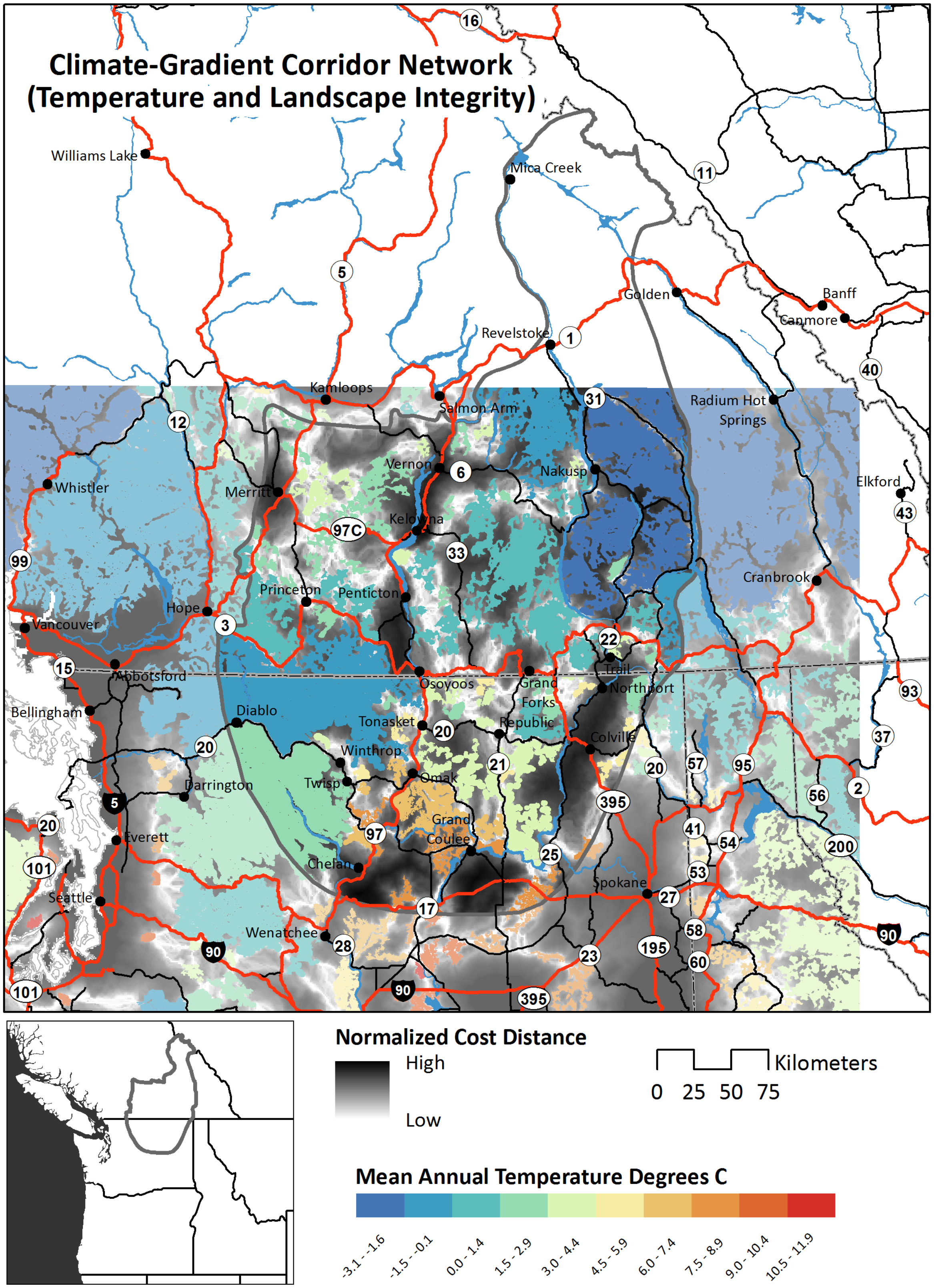
Appendix H.1a. WHCWG Statewide Analysis: Mule Deer Corridor Model

iii) Extent: Washington-British Columbia Transboundary Region



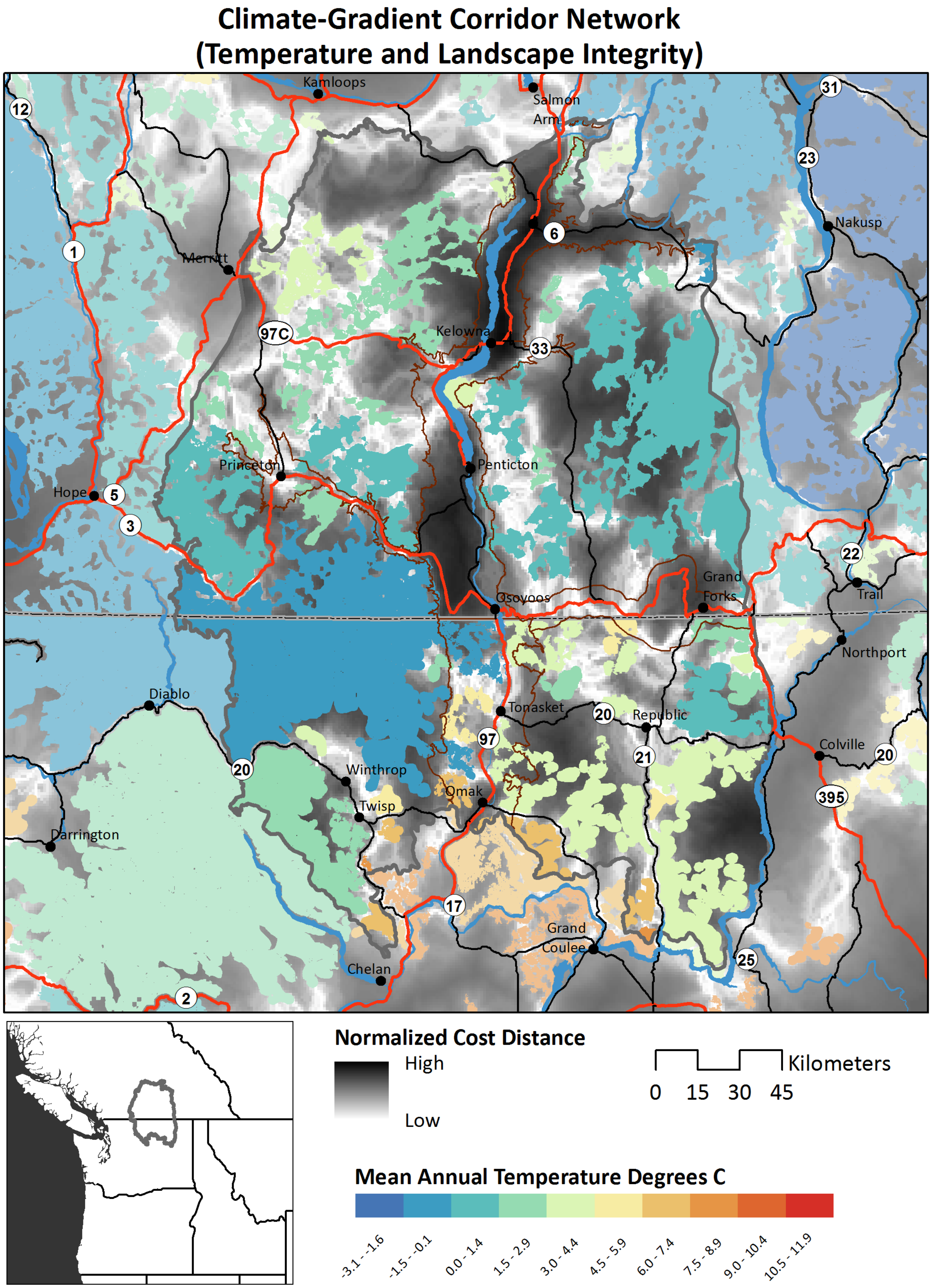
Appendix H.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Model

i) Extent: Okanagan Nation Territory



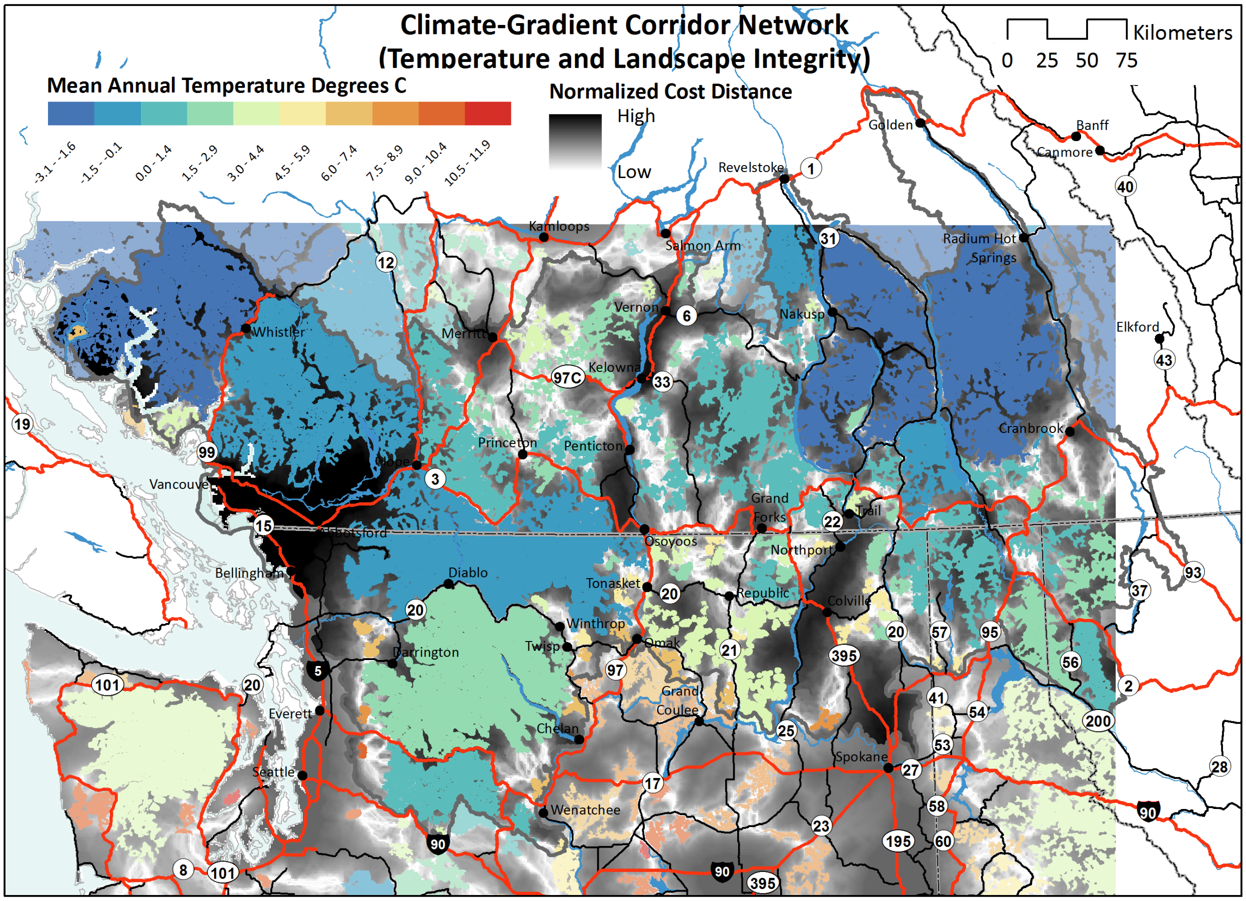
Appendix H.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Model

ii) Extent: Okanagan-Kettle Region



Appendix H.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix H.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary mule deer habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence mule deer habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The Mule deer conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to Mule deer habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the mule deer conceptual model included:

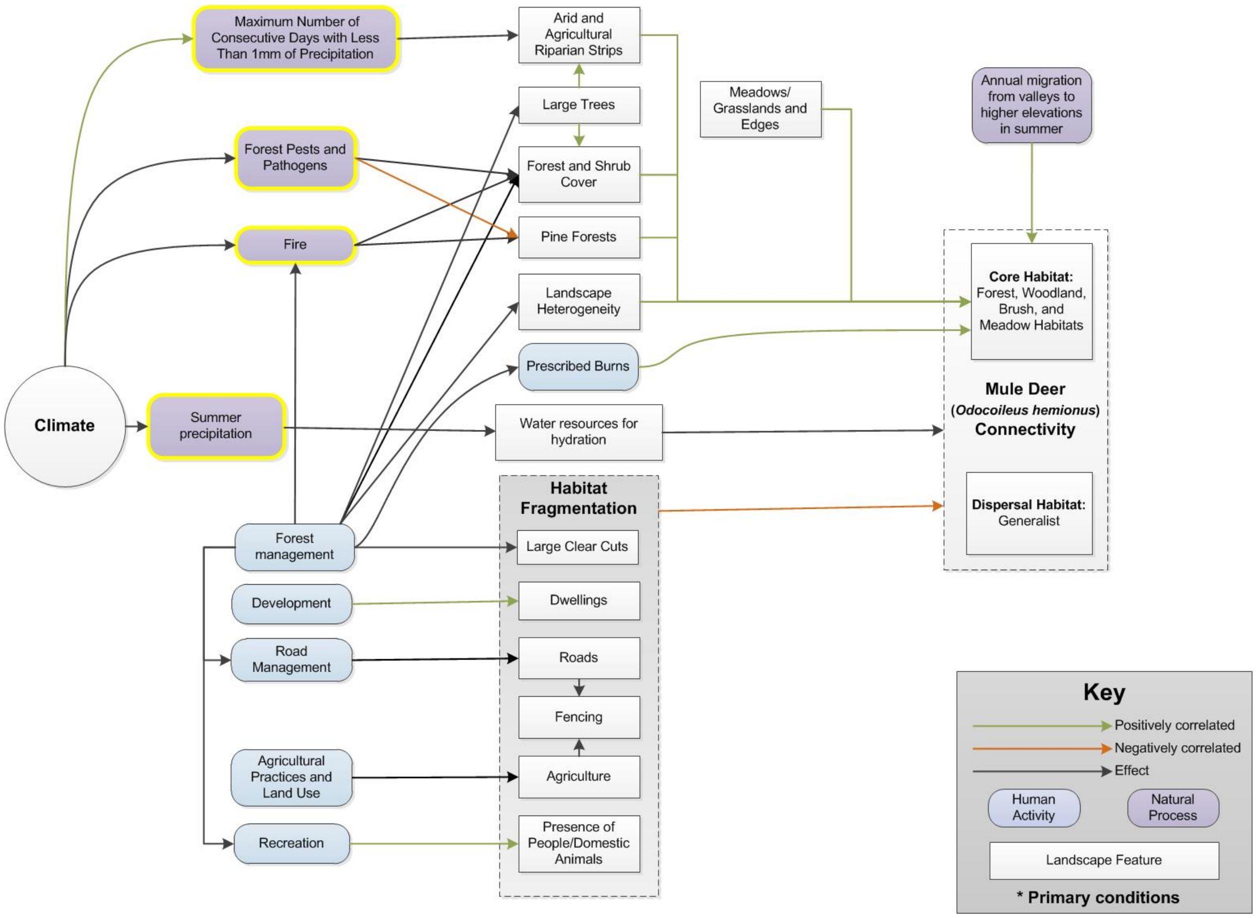
- Alison Peatt, RPBio, Environmental Planner for South Okanagan-Similkameen Communities
- Penticton Indian Band (community member/hunting specialist)

Key references used to create the mule deer conceptual model included:

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2013. Washington Connected Landscapes Project: Analysis of the Columbia Plateau Ecoregion. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA.

Appendix H.2. Conceptual model of mule deer habitat connectivity



Appendix H.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[vii] Both models use the A2 (high) emissions scenario.[viii] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[ix]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

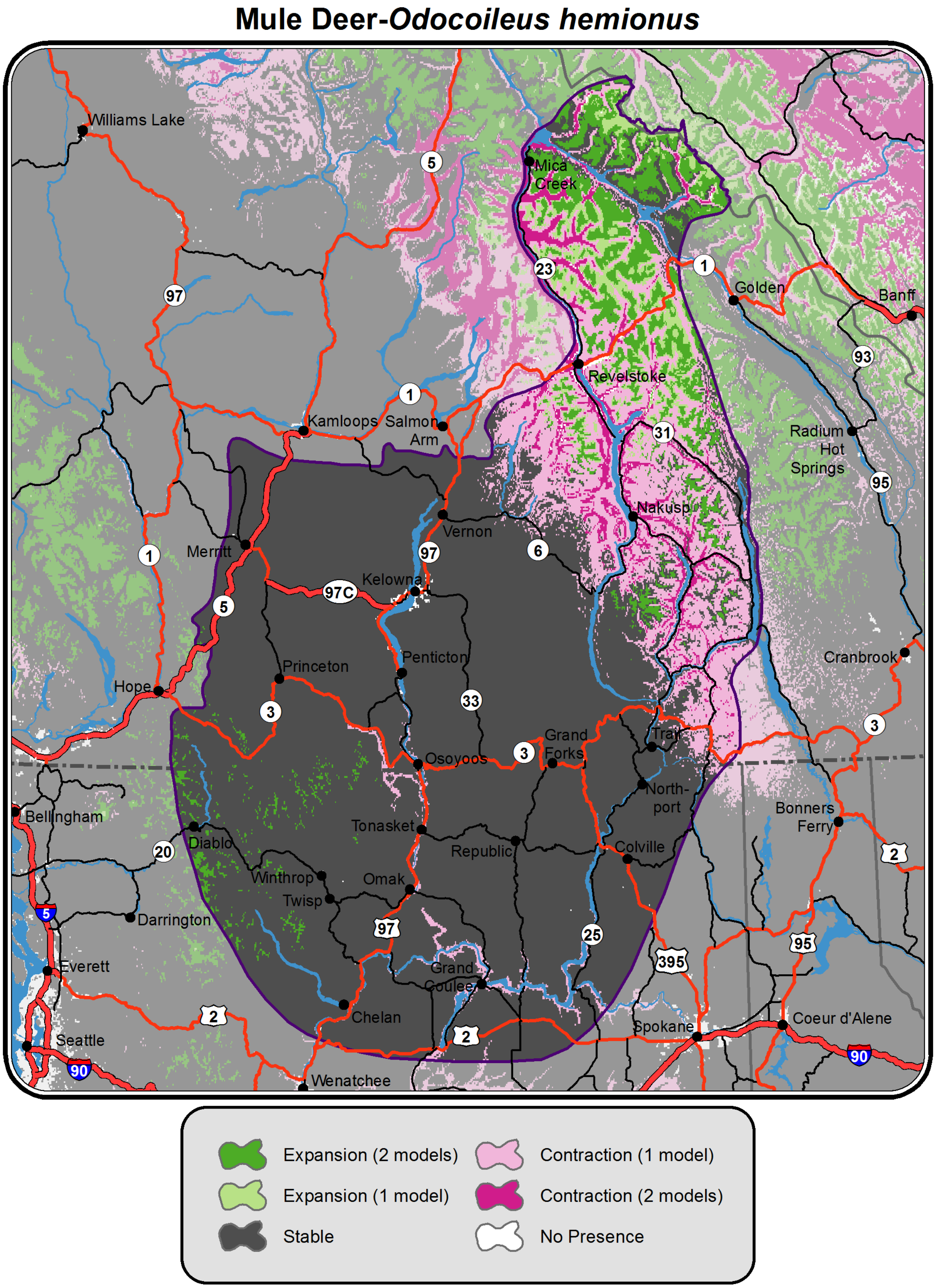
[vii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[viii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[ix] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

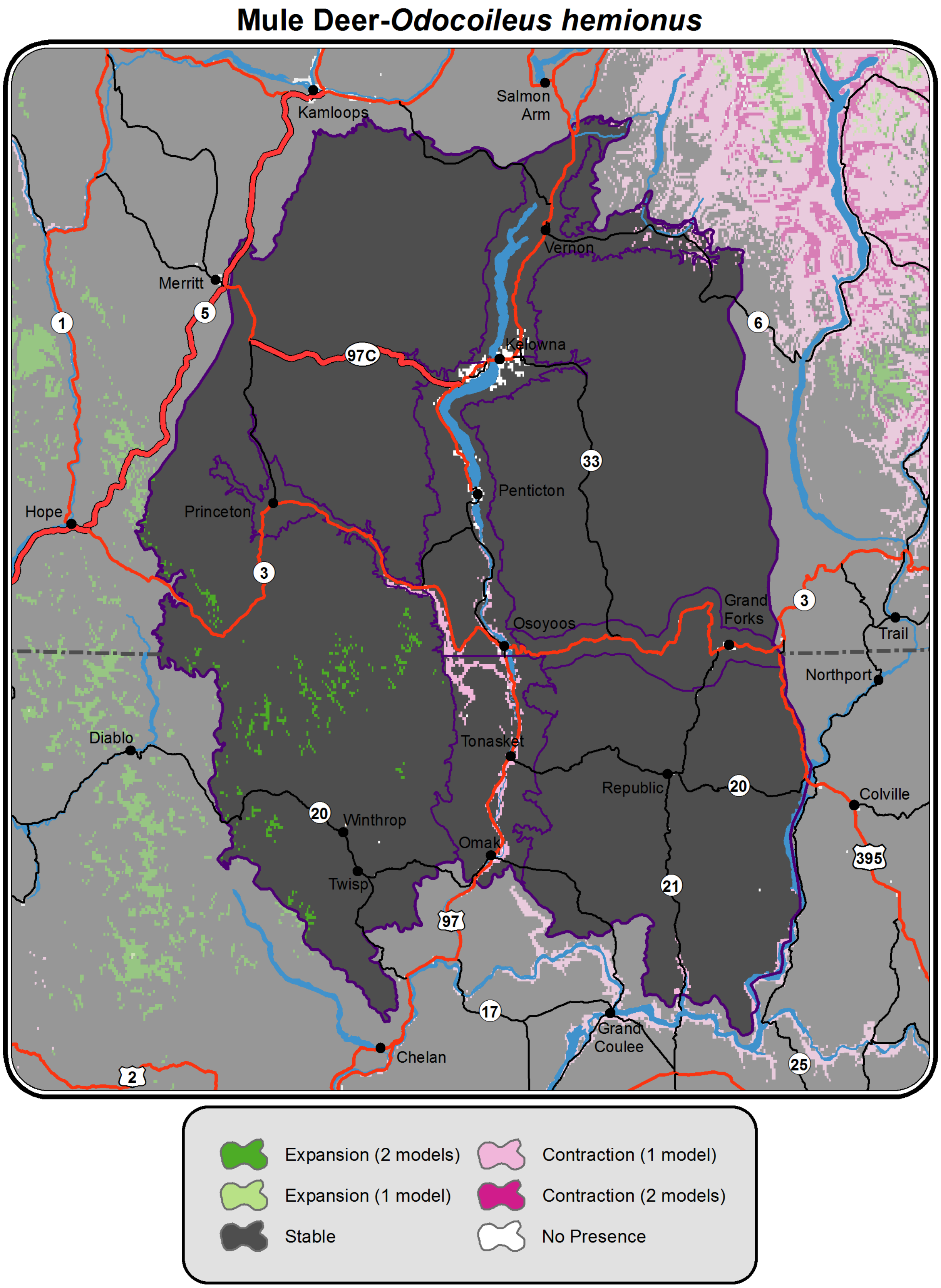
Appendix H.3. Mule Deer Climatic Niche Model

i) Extent: Okanagan Nation Territory



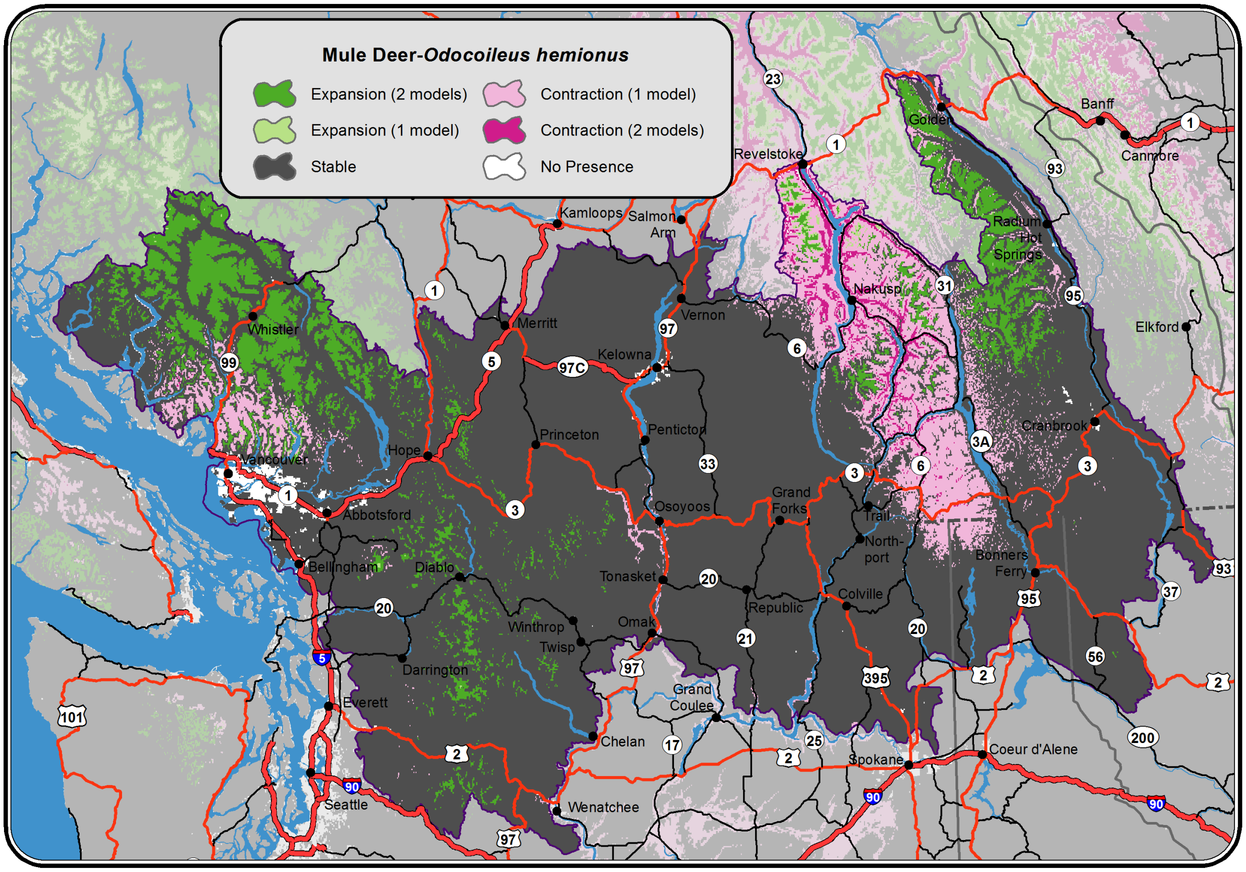
Appendix H.3. Mule Deer Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



Appendix H.3. Mule Deer Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix H.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[x] Both models also use the A2 (high) emissions scenario.[xi]

a) **Biome Climatic Niche Vegetation Model.**[xii] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xiii] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

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[x] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

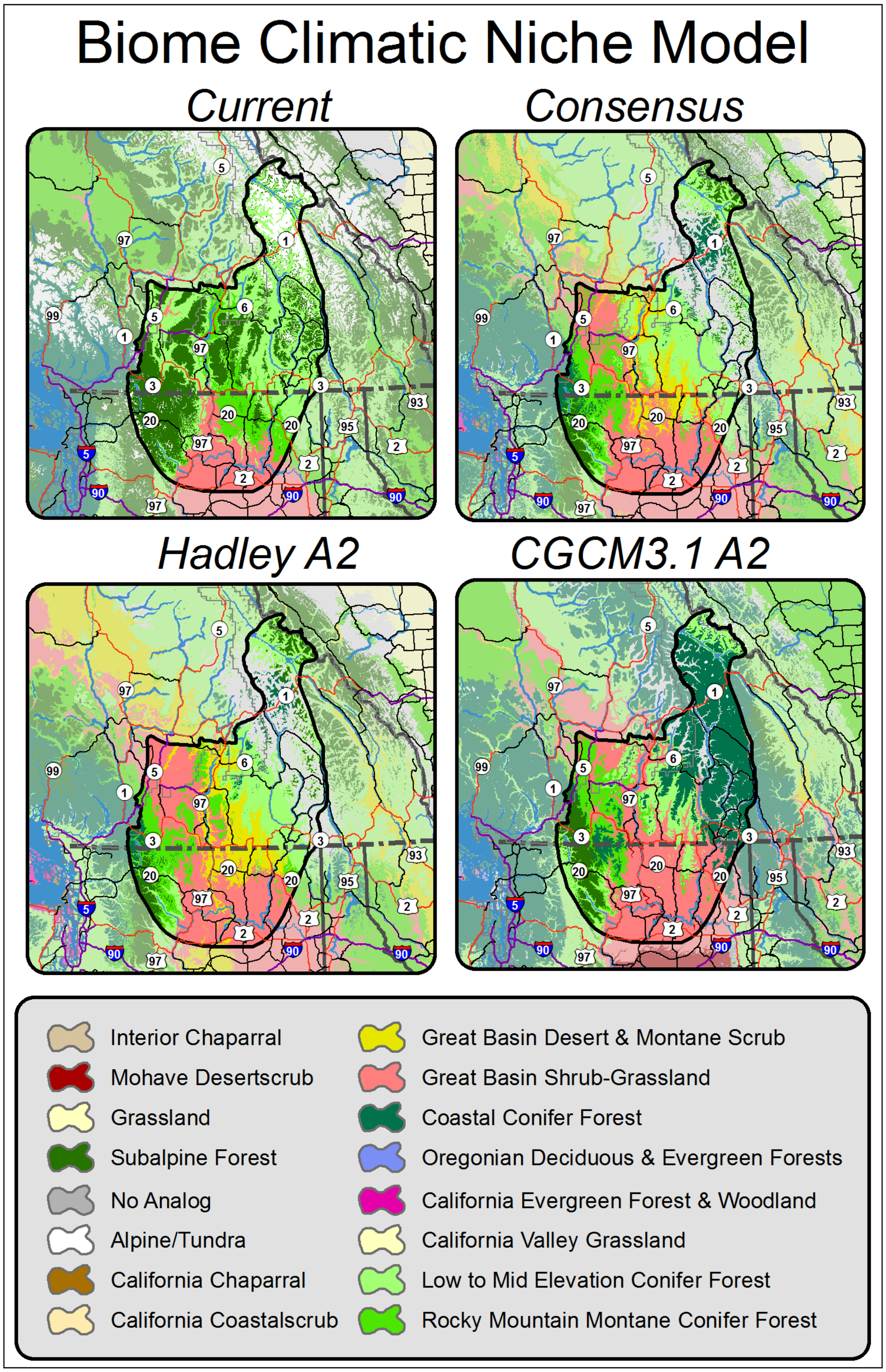
[xi] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

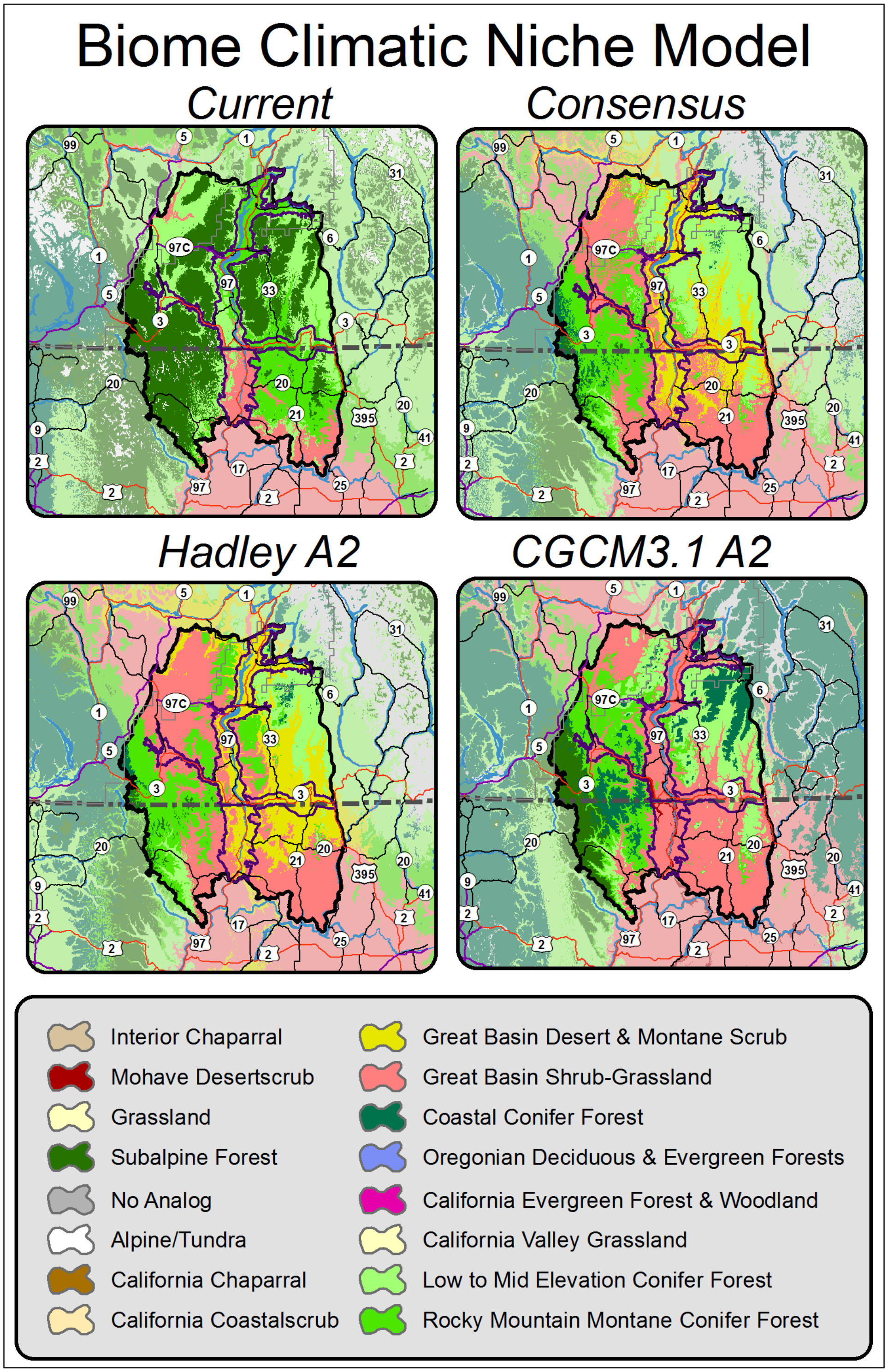
Appendix H.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



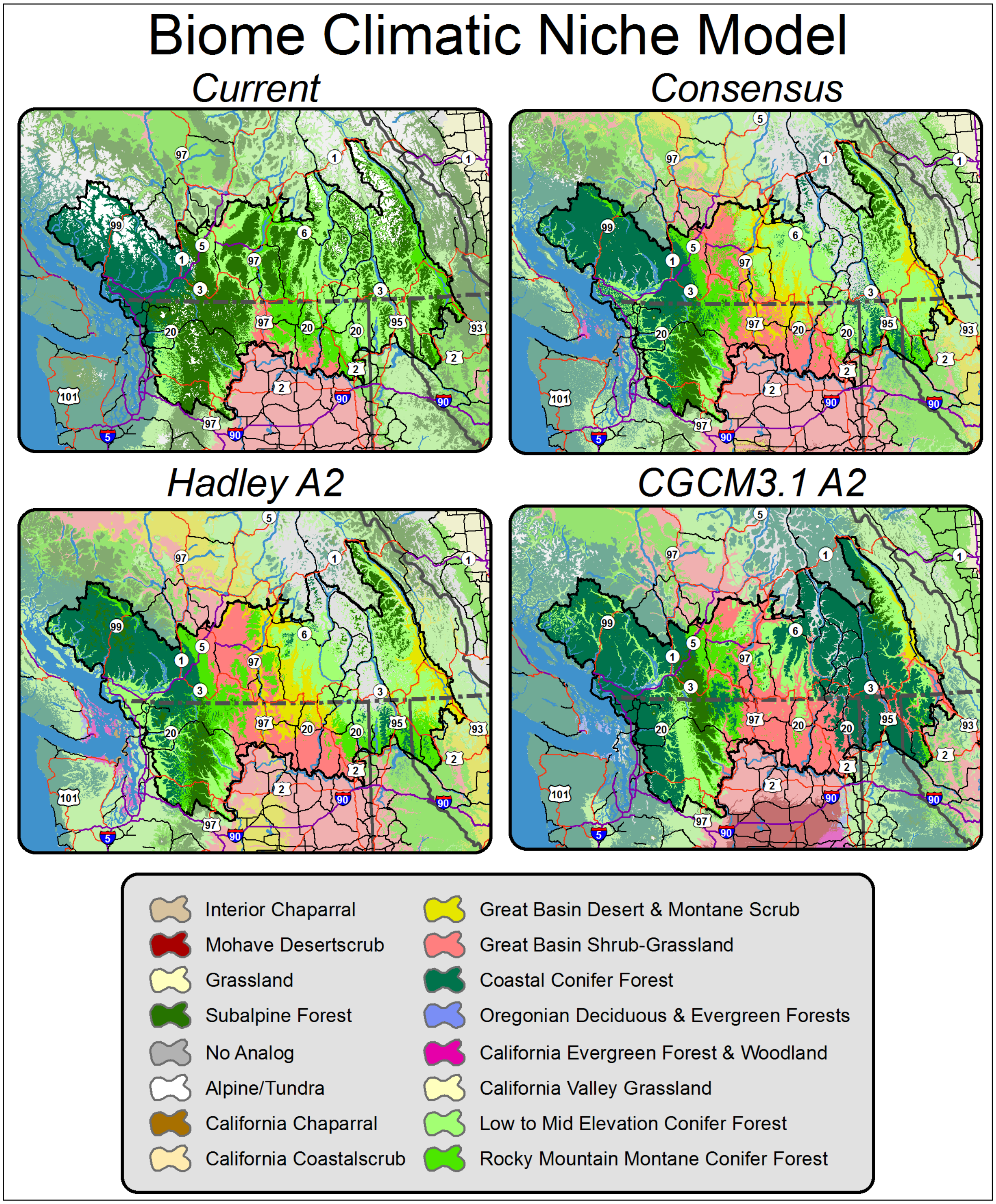
Appendix H.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



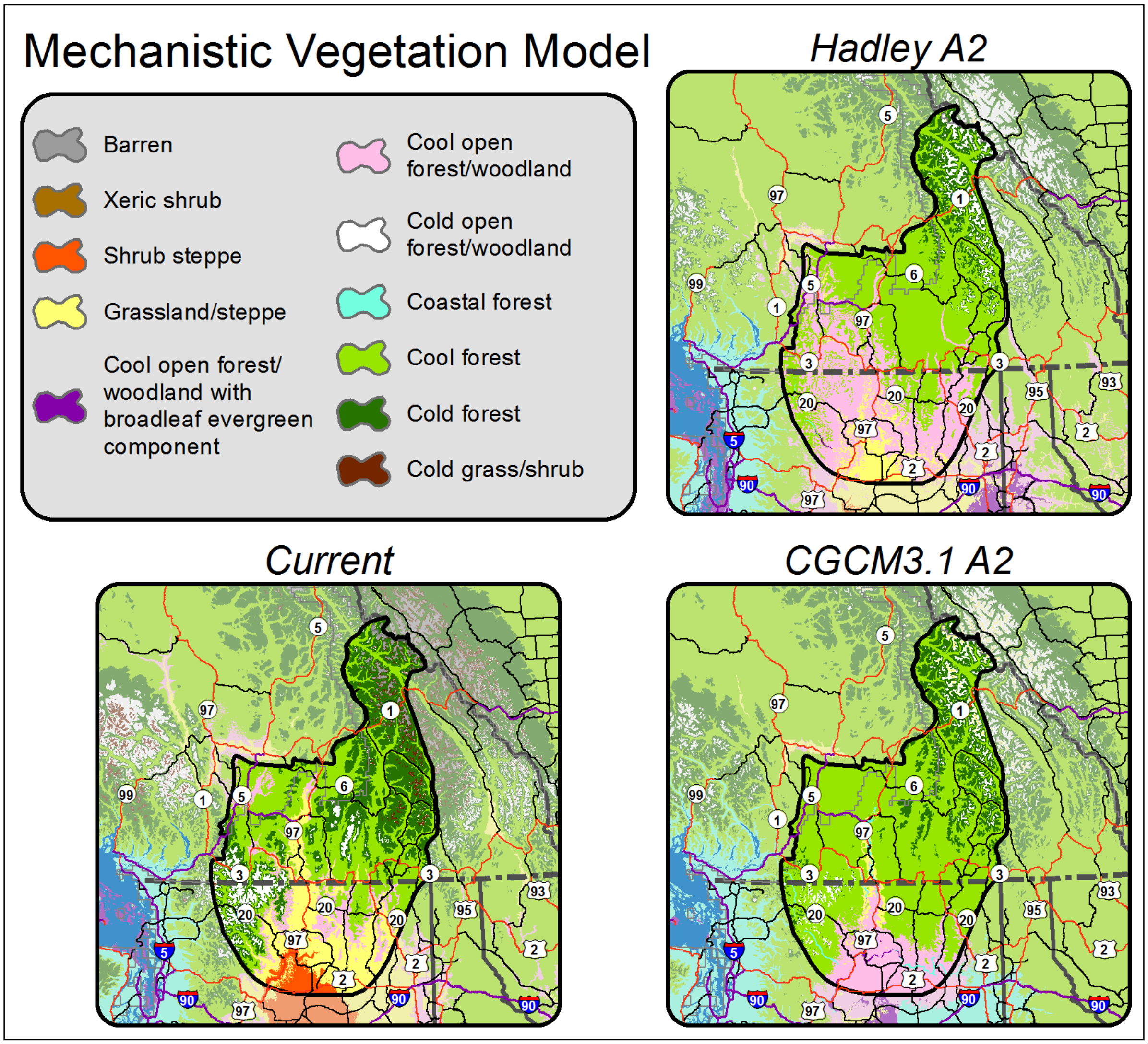
Appendix H.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



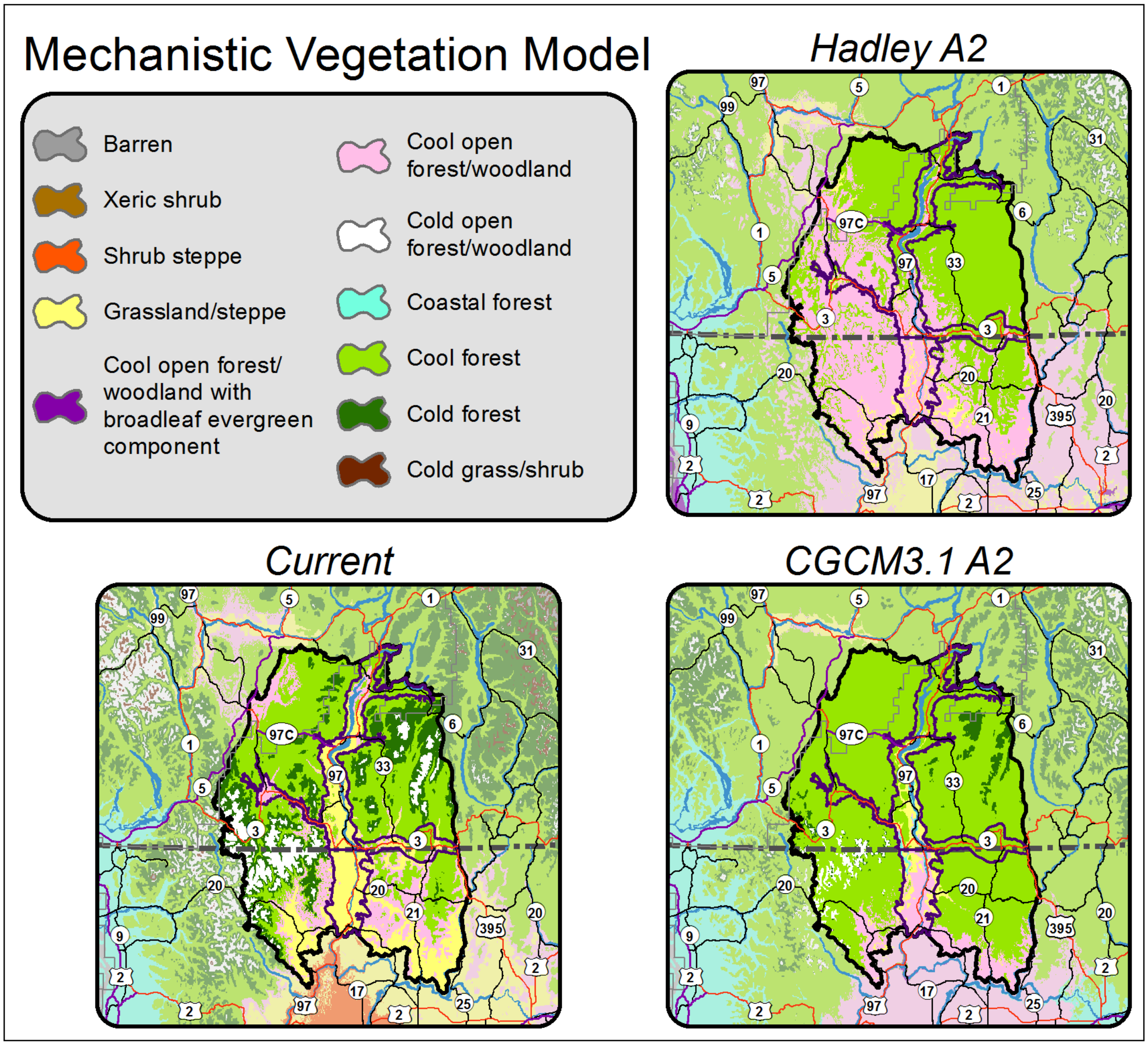
Appendix H.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



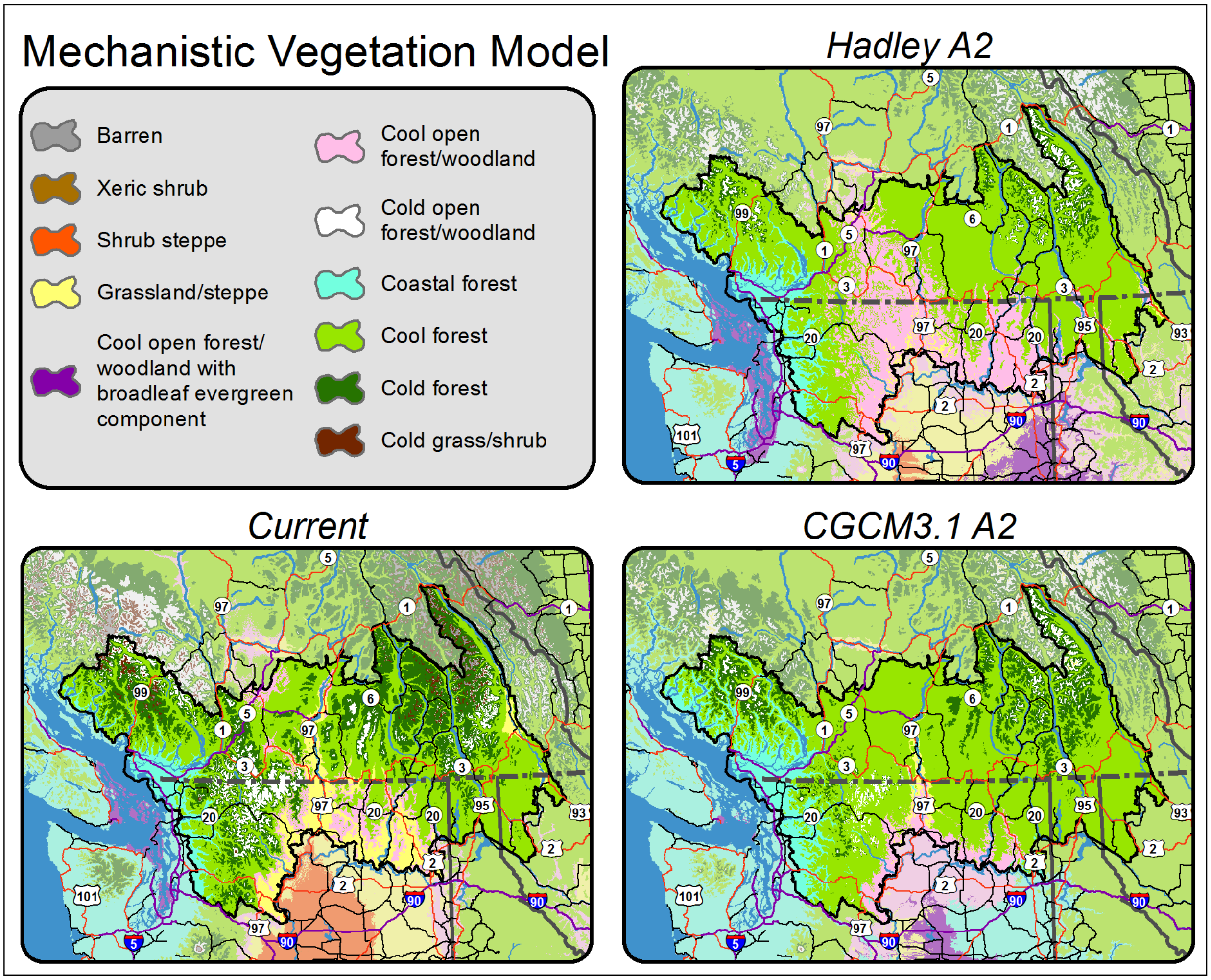
Appendix H.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix H.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix H.5. Projected Changes in Probability of Mountain Pine Beetle Survival

Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xiv,xv]

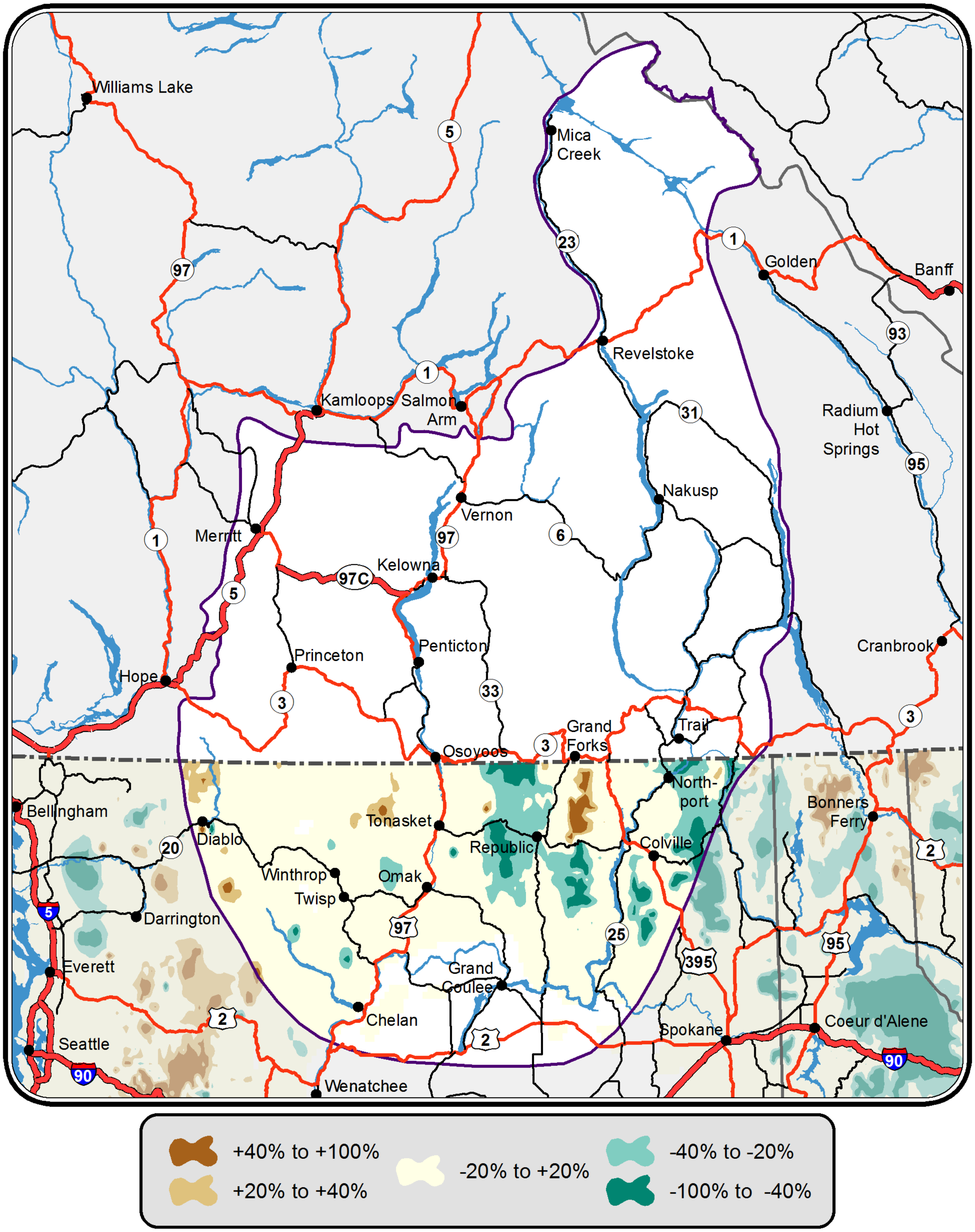
[xiv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.

[xv] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation.[xiv] Projections are only available for the United States.

Appendix H.5. Probability of Mountain Pine Beetle Survival

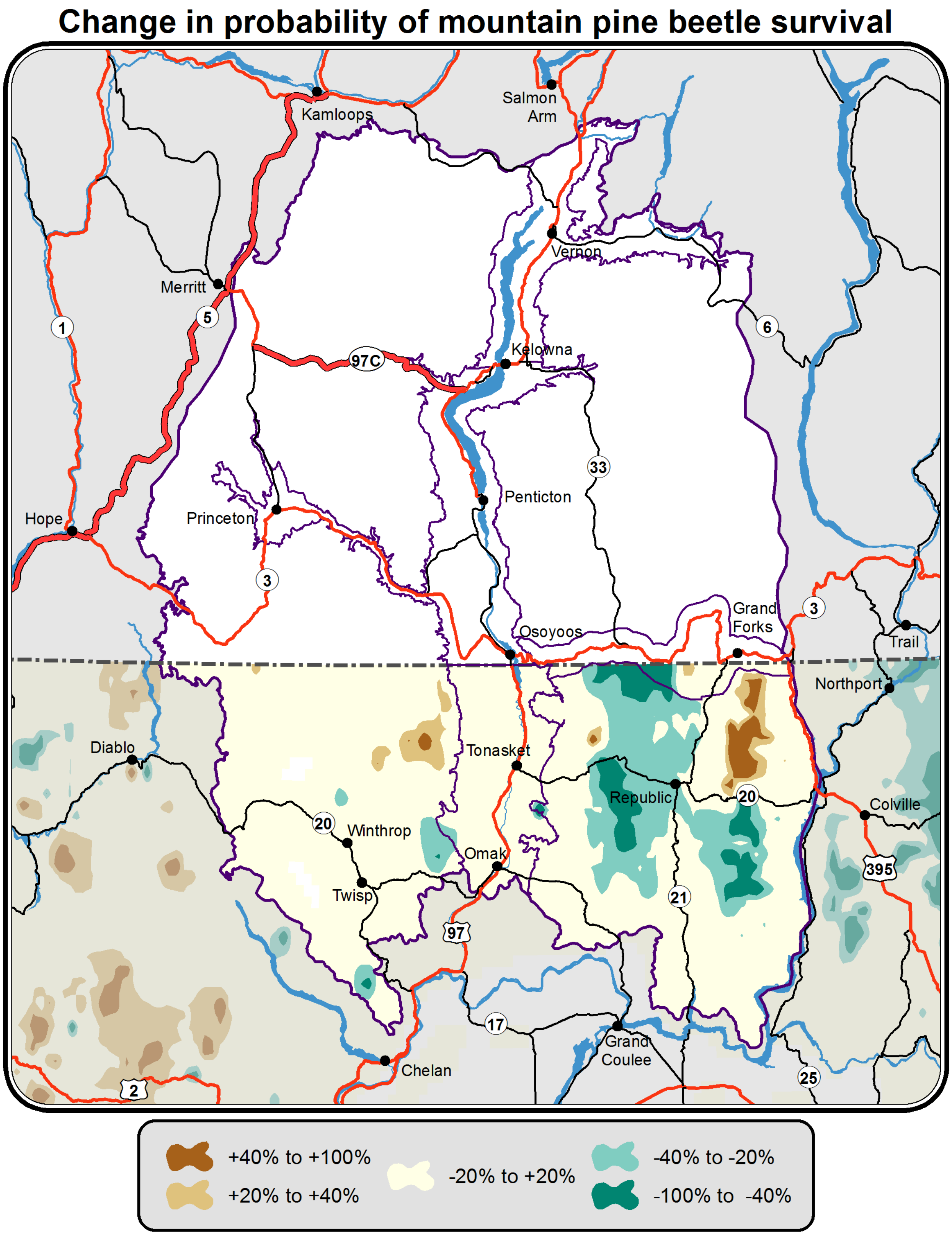
i) Extent: Okanagan Nation Territory

Change in probability of mountain pine beetle survival



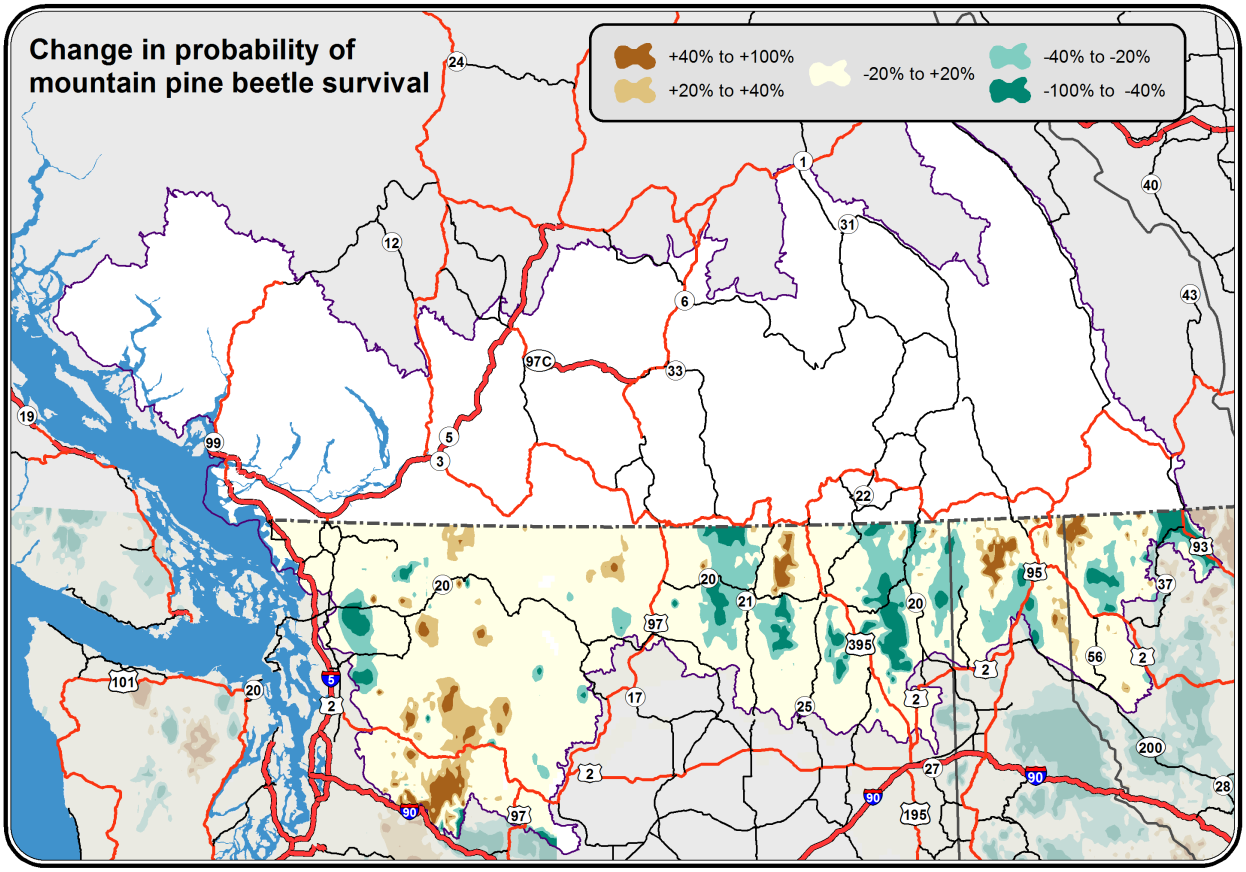
Appendix H.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region



Appendix H.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region



Appendix H.6. Projected Changes for Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on mule deer connectivity.[xvi] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[8] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[9] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Water Deficit, July-September.** This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

b) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

c) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile). This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.[xvii]

d) **Dry Spell Duration.** This map shows the projected change, in percent, in the maximum number of consecutive days with less than 1 mm of precipitation. Projected change in dry spell duration is depicted by the brown to green shading.

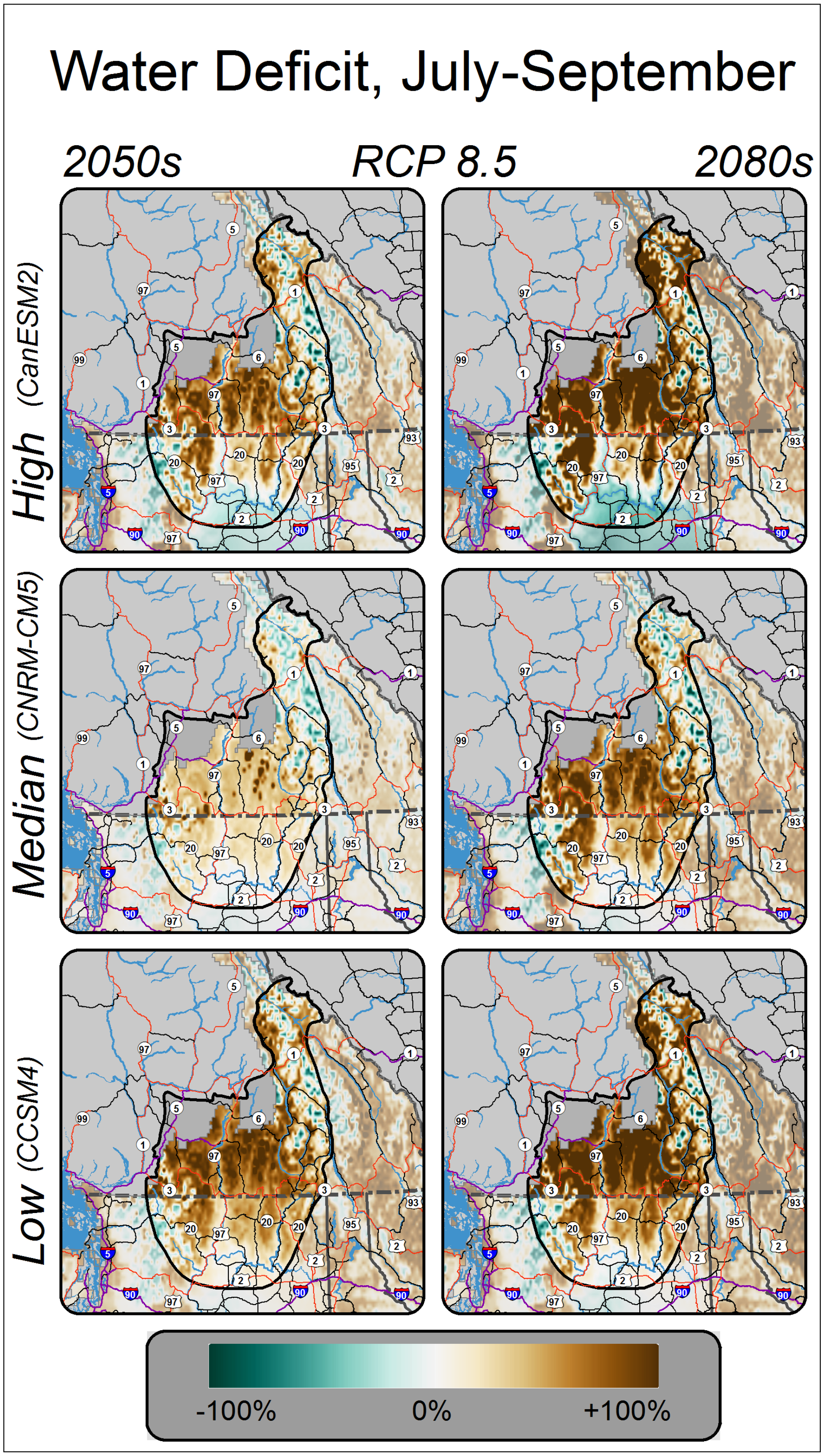
e) **Total Summer Precipitation, June-August.** This map shows the projected change, in percent, in total summer (June-August) precipitation. Projected changes in total summer precipitation are depicted by the teal to brown shading.

[xvi] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xvii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

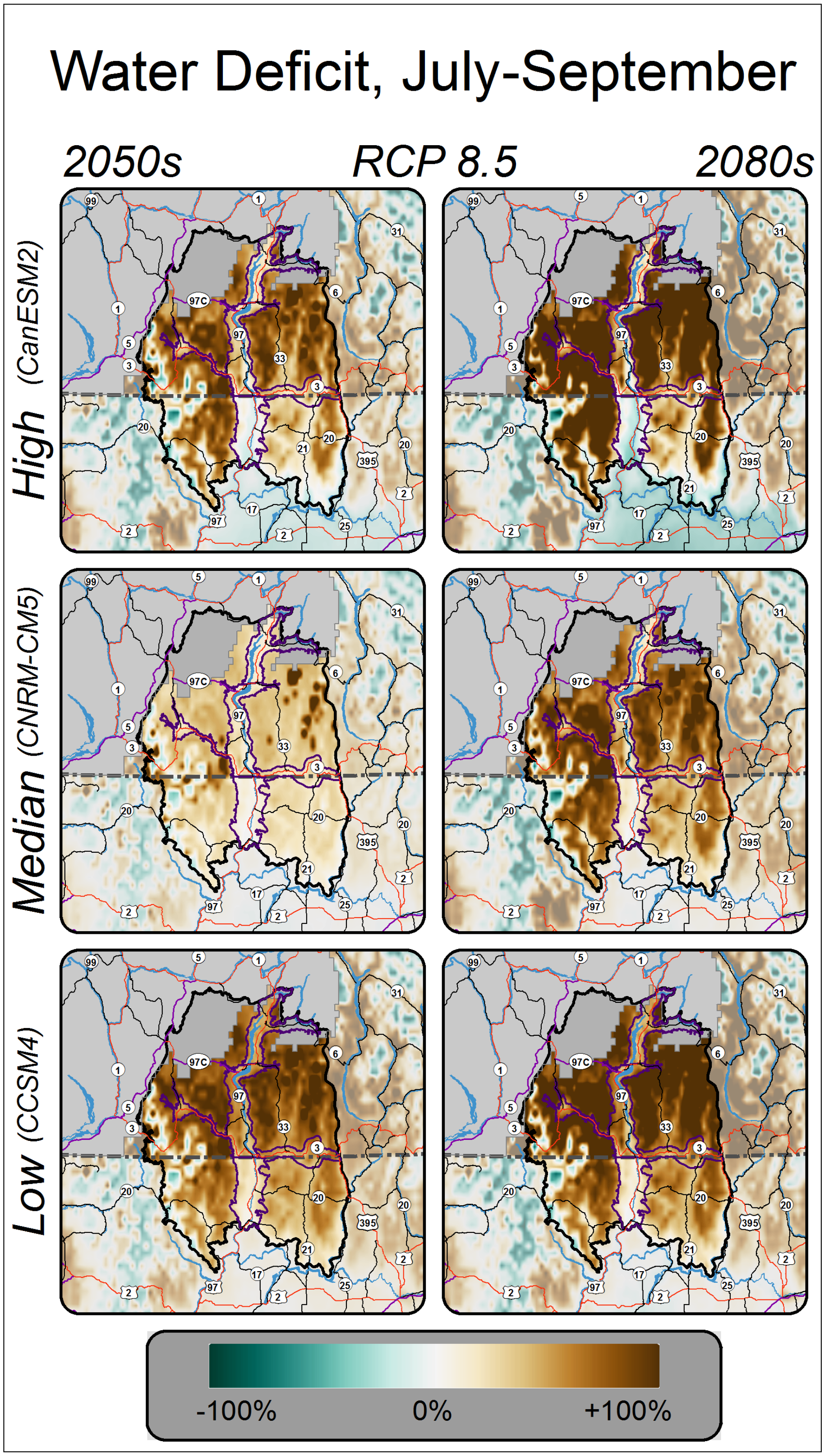
Appendix H.6a. Water Deficit, July-September

i) Extent: Okanagan Nation Territory



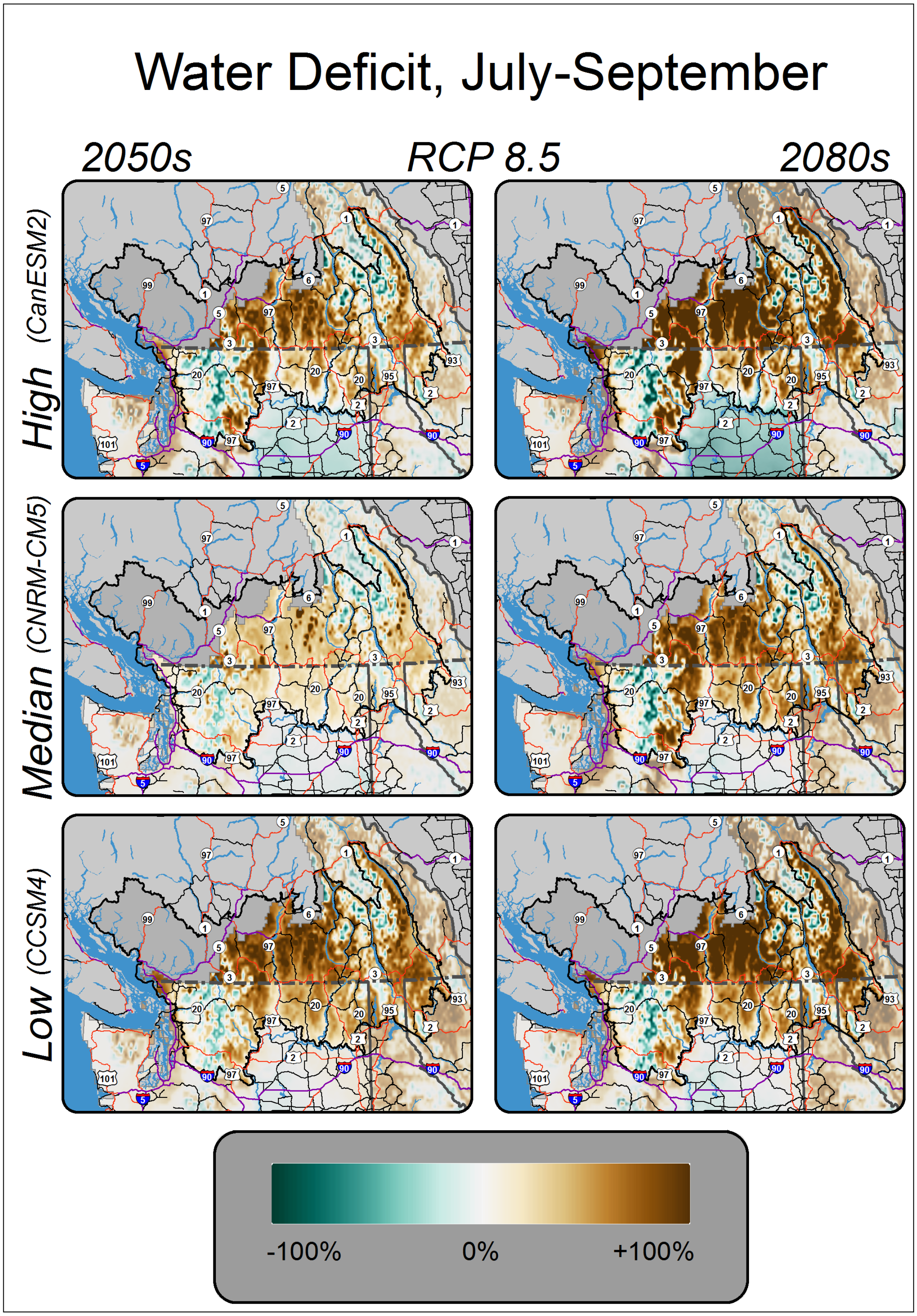
Appendix H.6a. Water Deficit, July-September

ii) Extent: Okanagan-Kettle Region



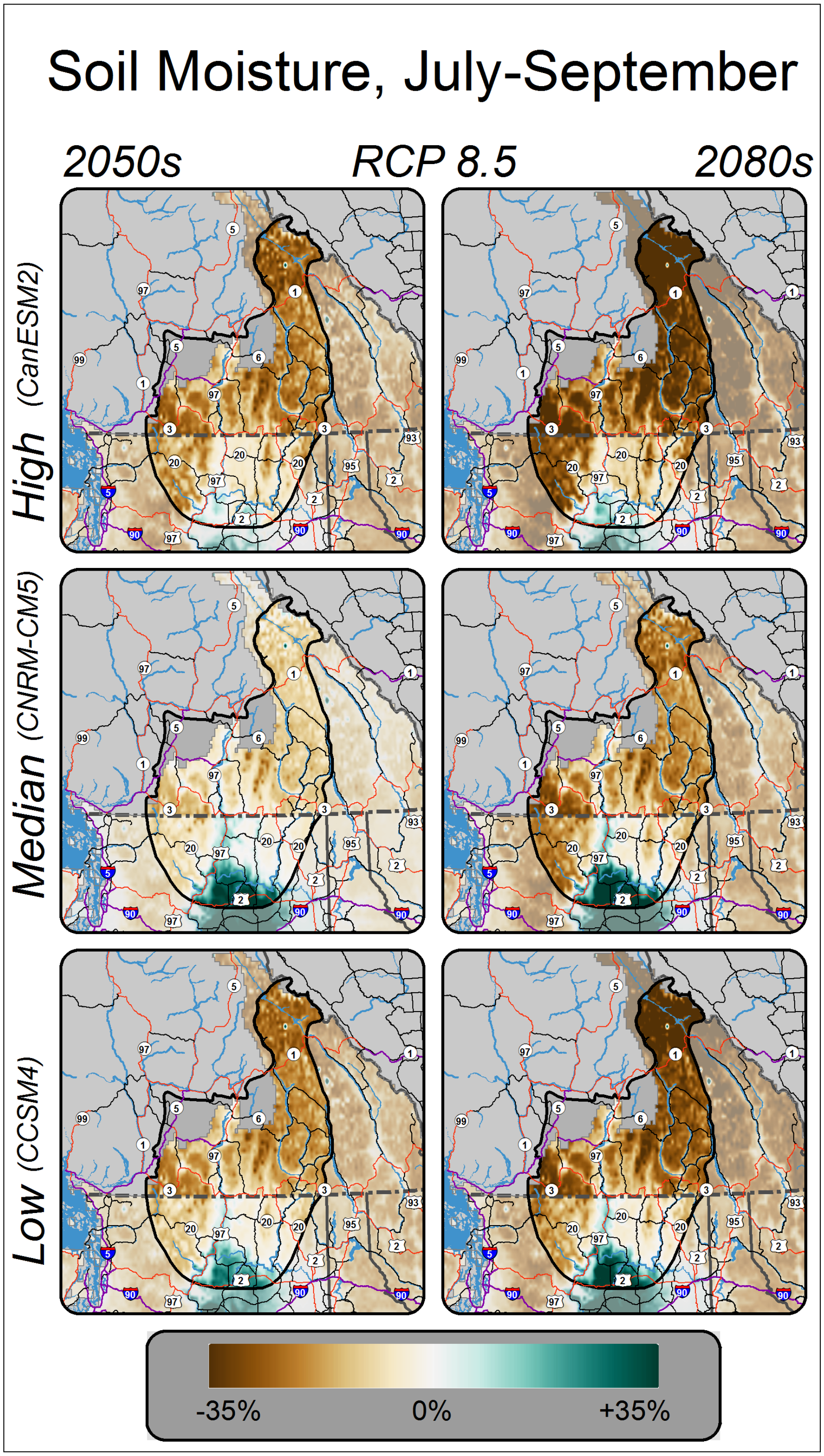
Appendix H.6a. Water Deficit, July-September

iii) Extent: Washington-British Columbia Transboundary Region



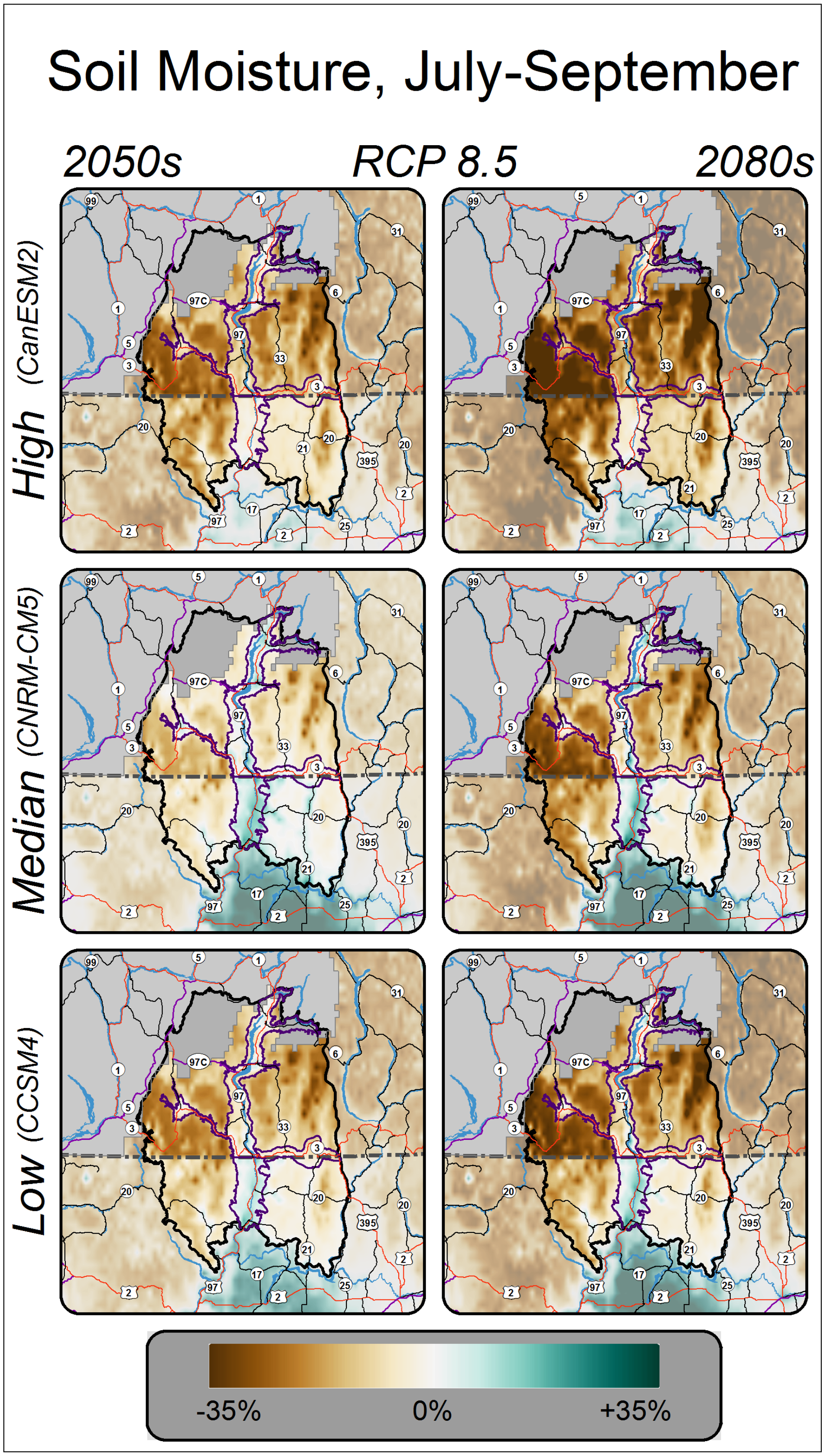
Appendix H.6b. Summer Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



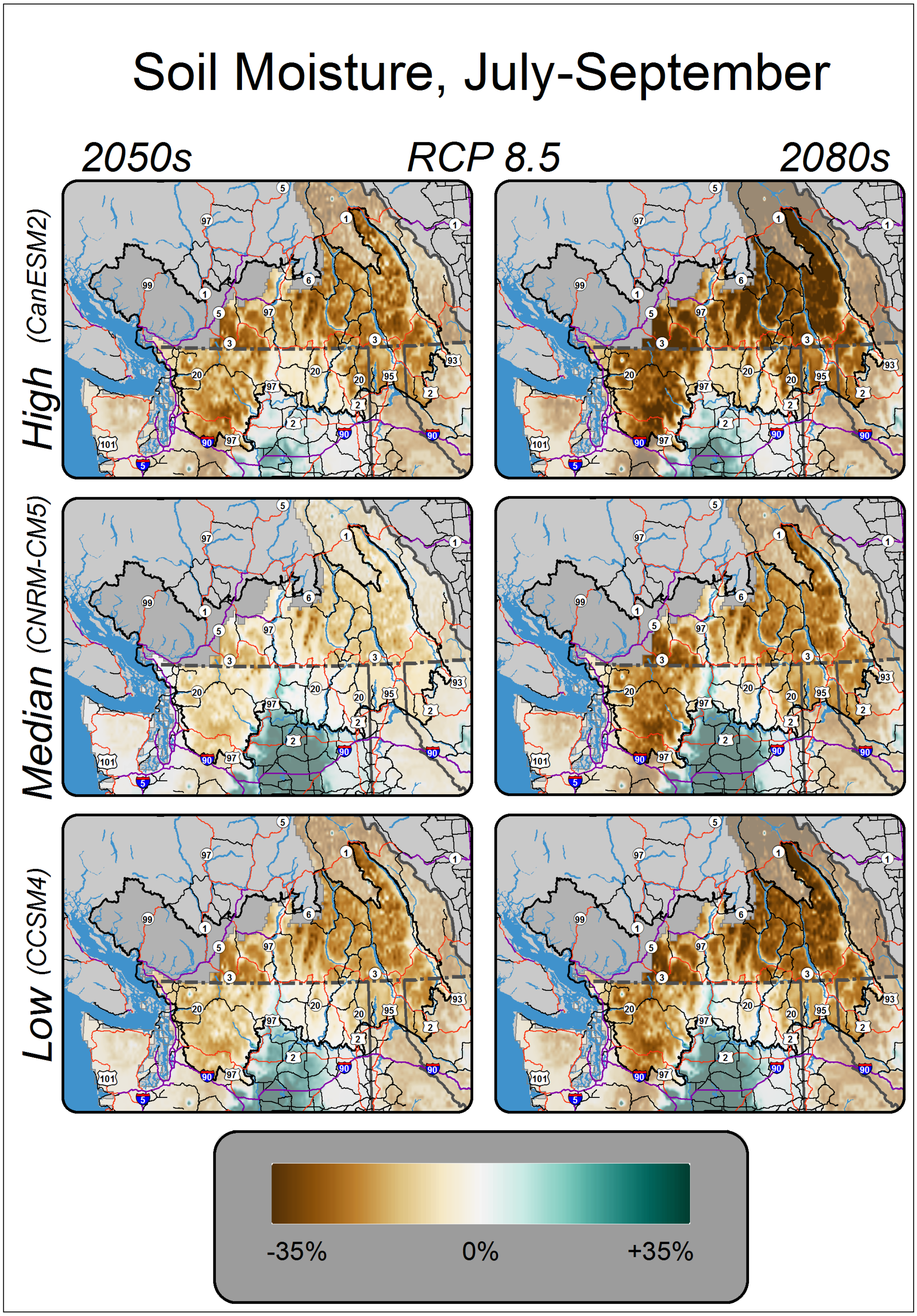
Appendix H.6b. Summer Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



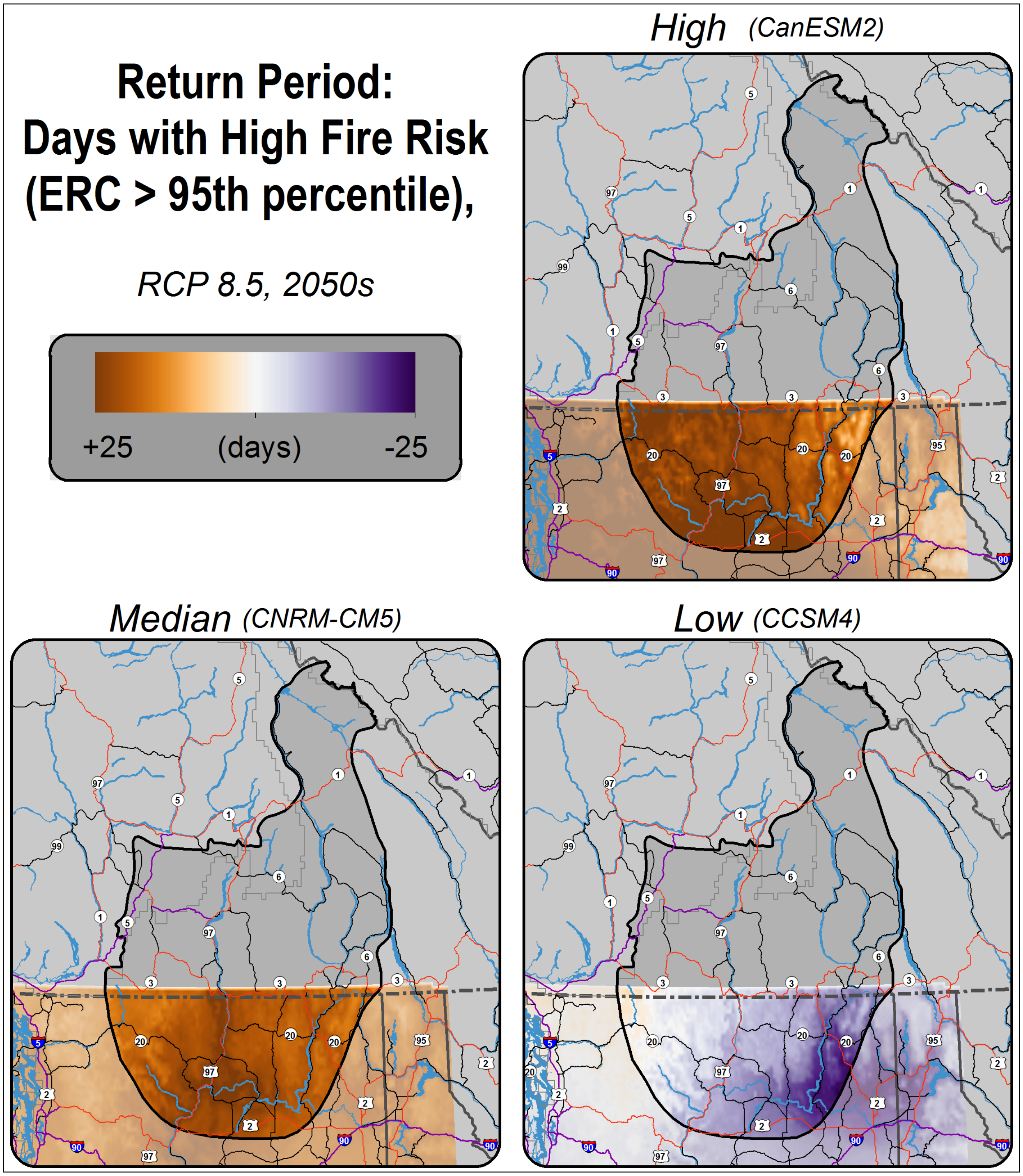
Appendix H.6b. Summer Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



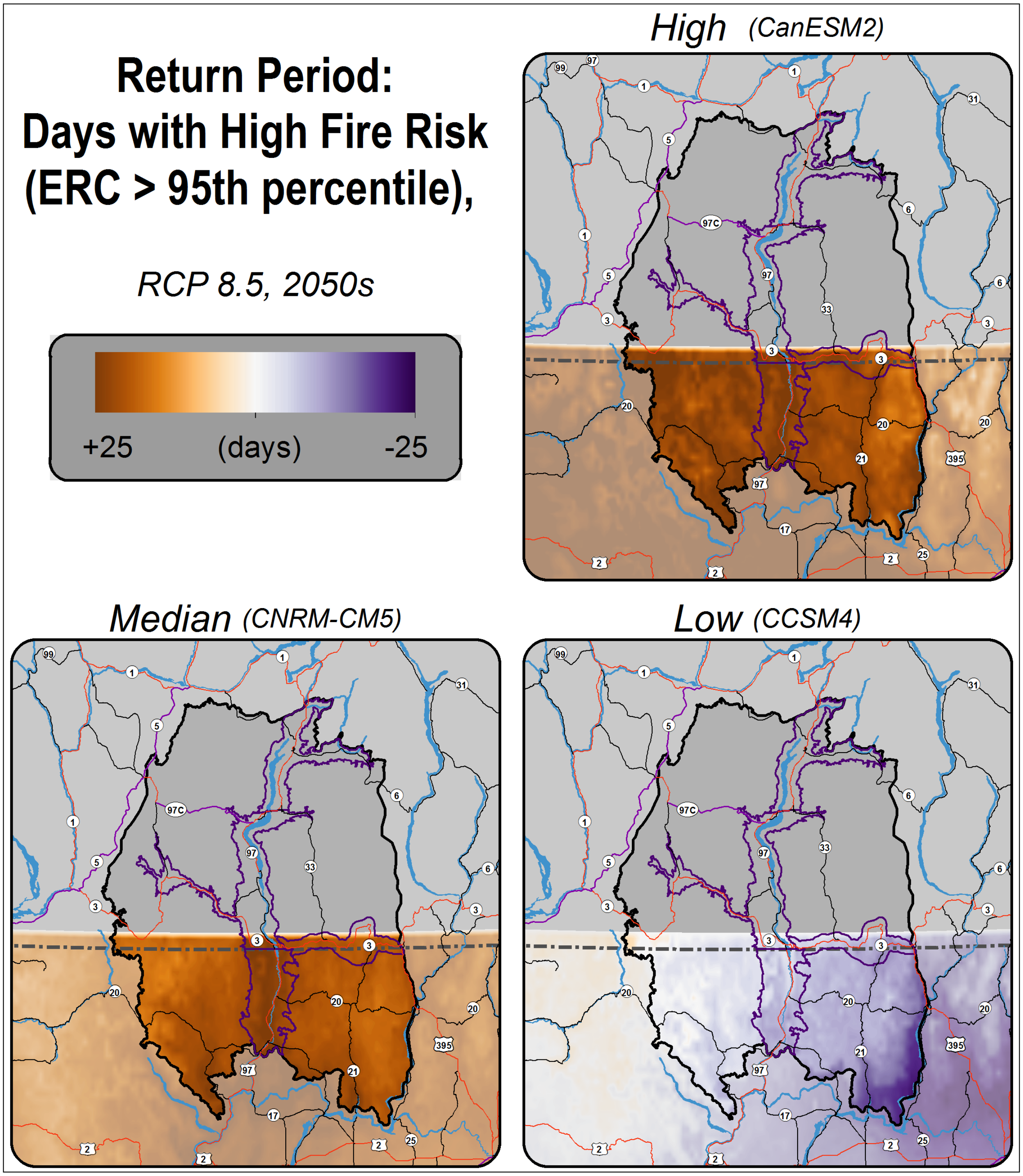
Appendix H.6c. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



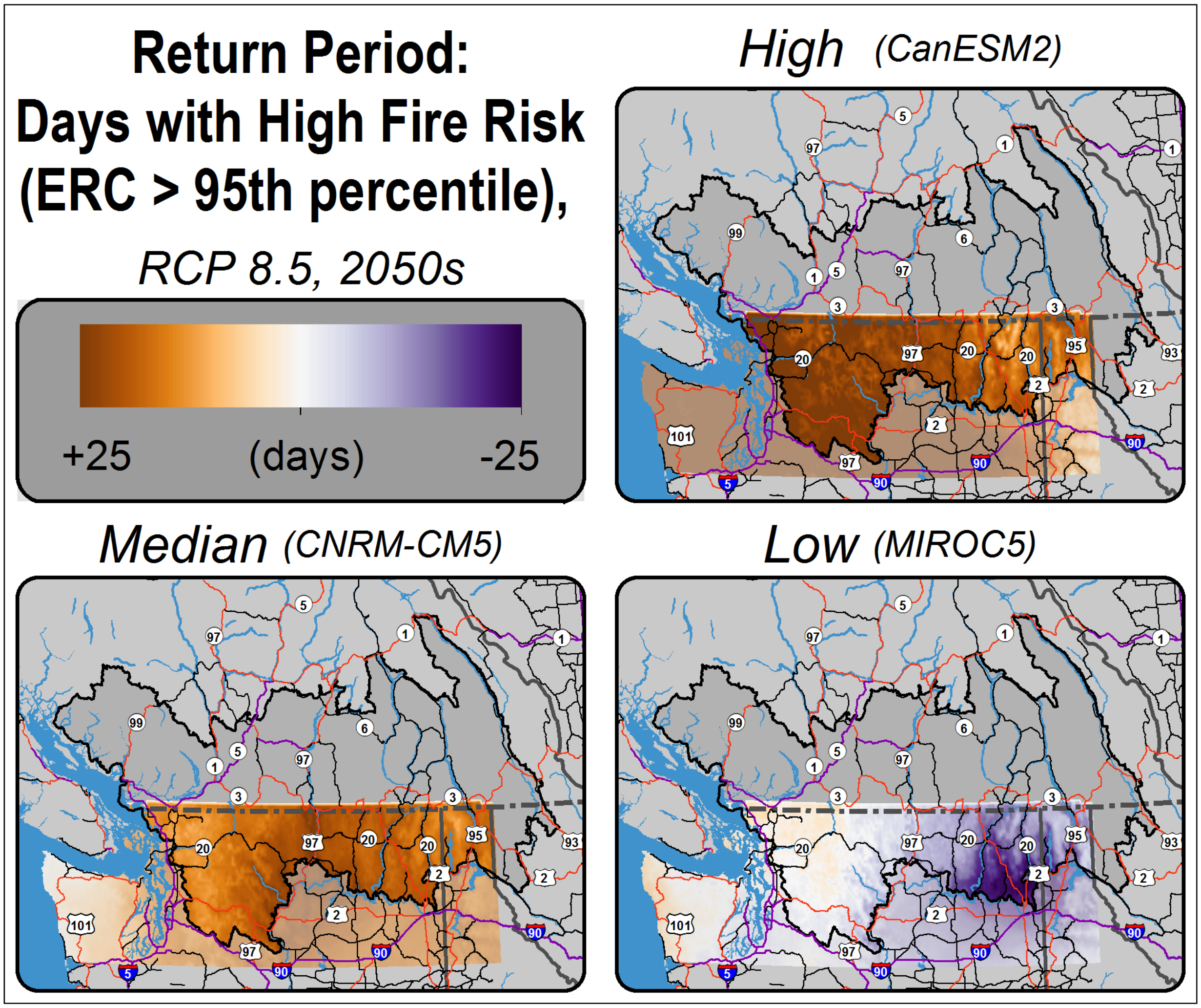
Appendix H.6c. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



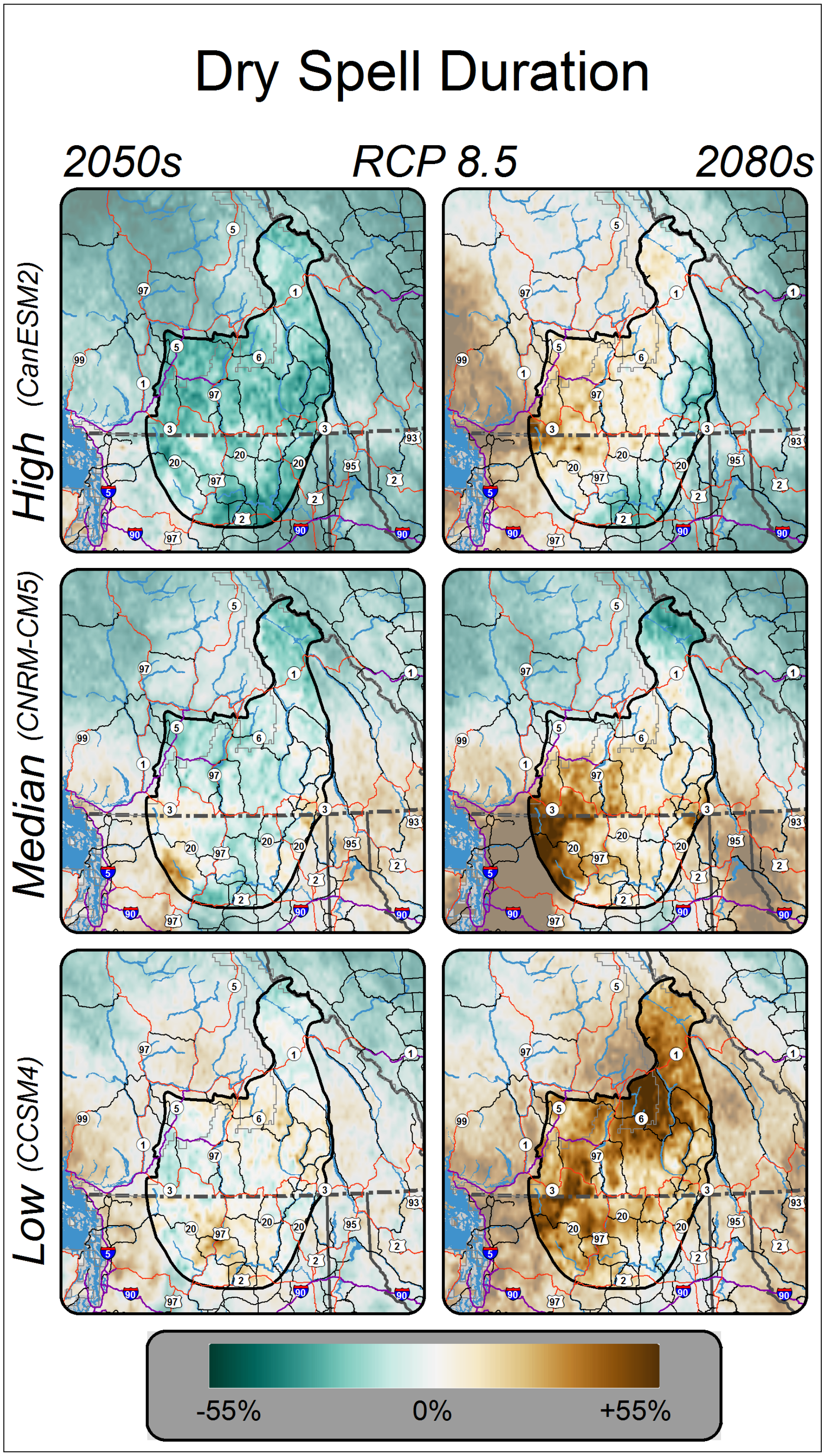
Appendix H.6c. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



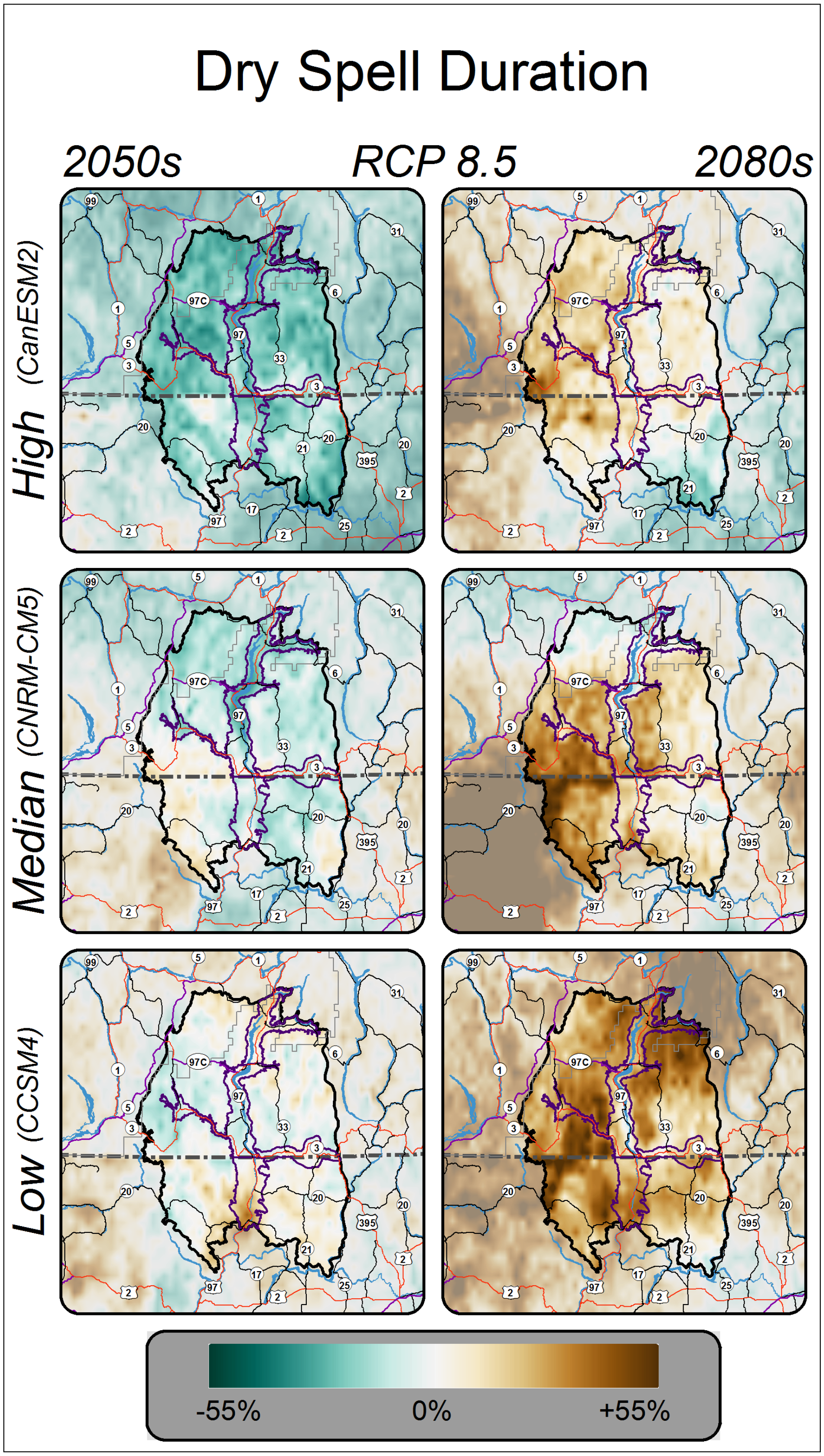
Appendix H.6d. Dry Spell Duration

i) Extent: Okanagan Nation Territory



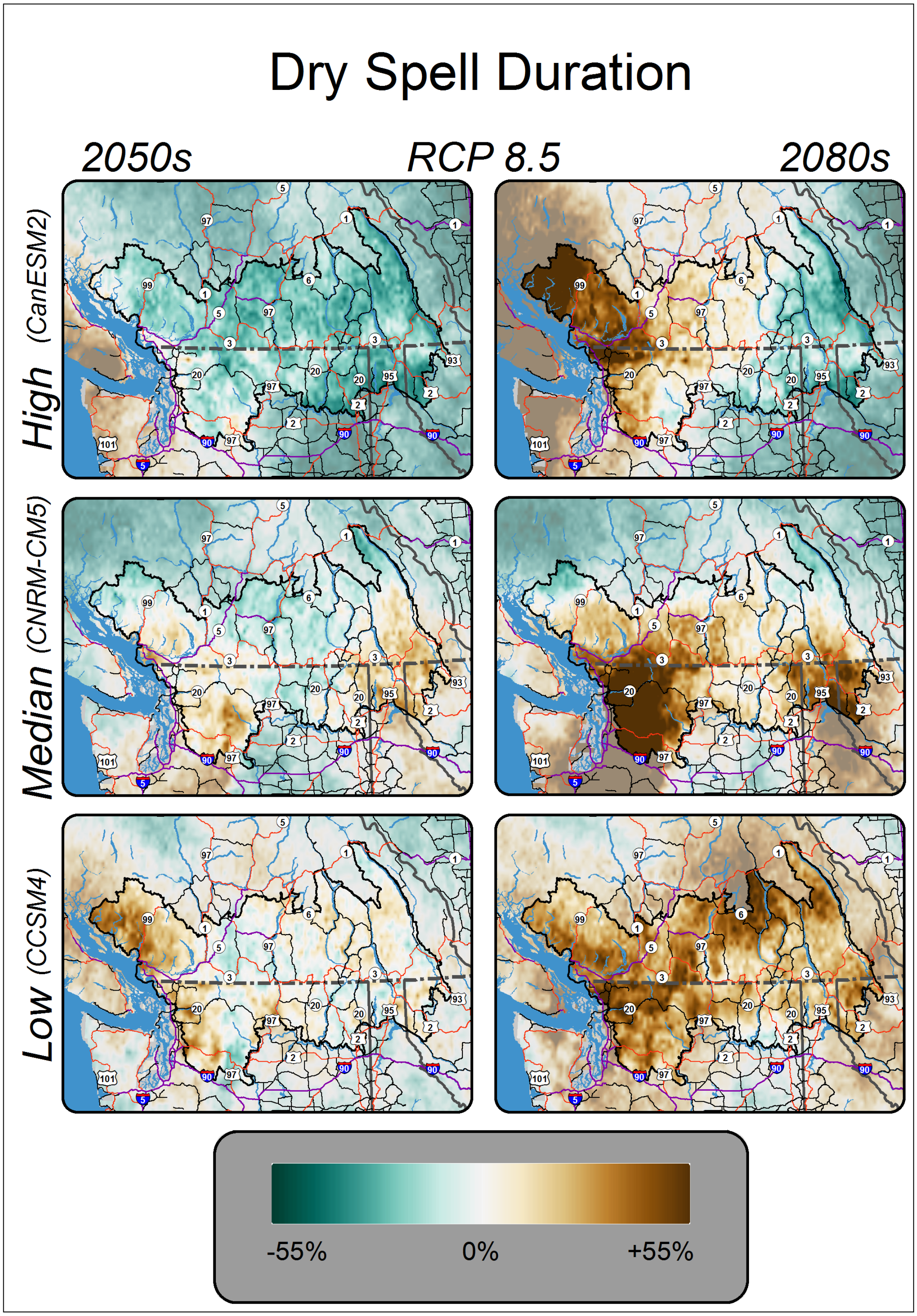
Appendix H.6d. Dry Spell Duration

ii) Extent: Okanagan-Kettle Region



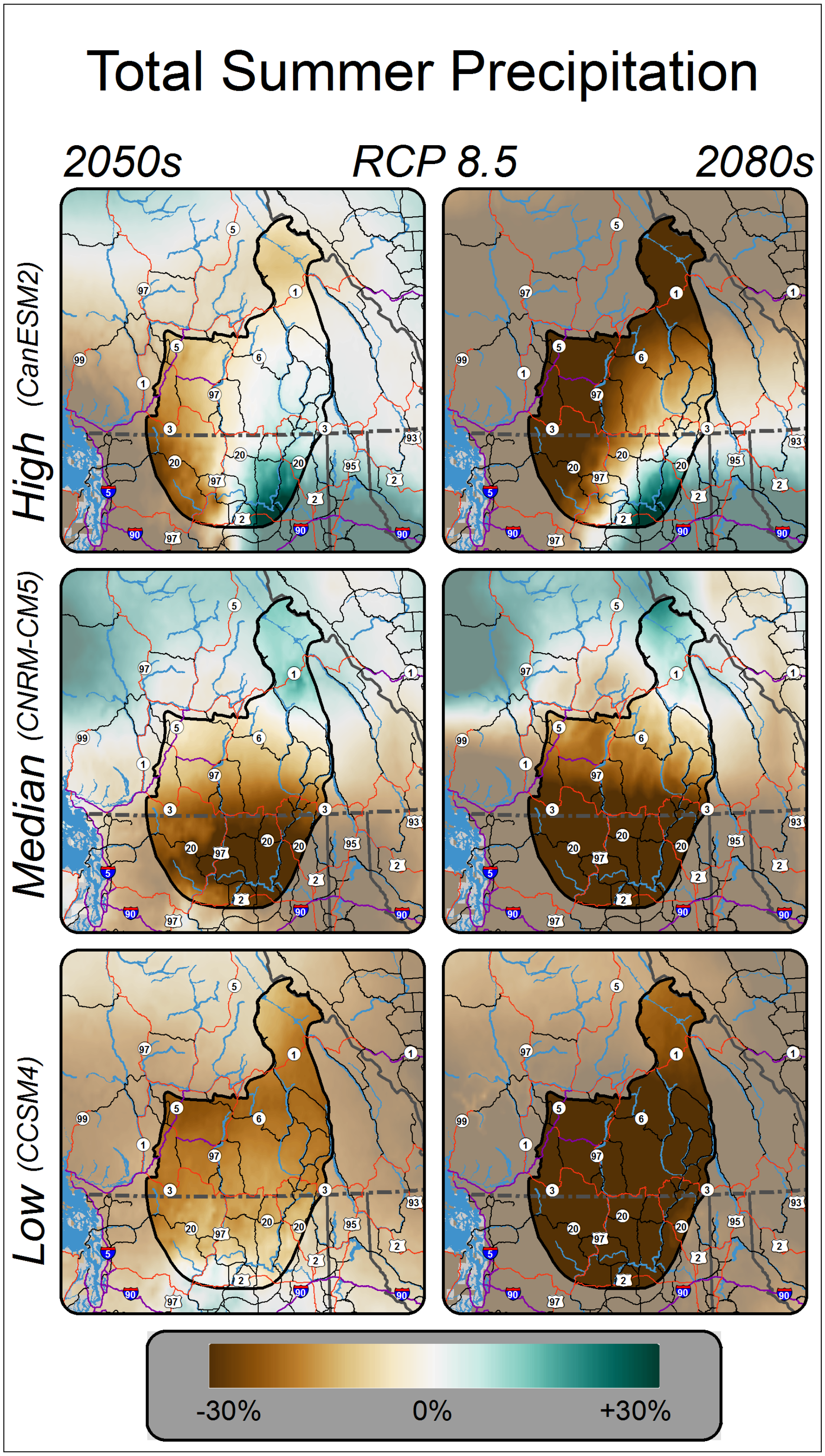
Appendix H.6d. Dry Spell Duration

iii) Extent: Washington-British Columbia Transboundary Region



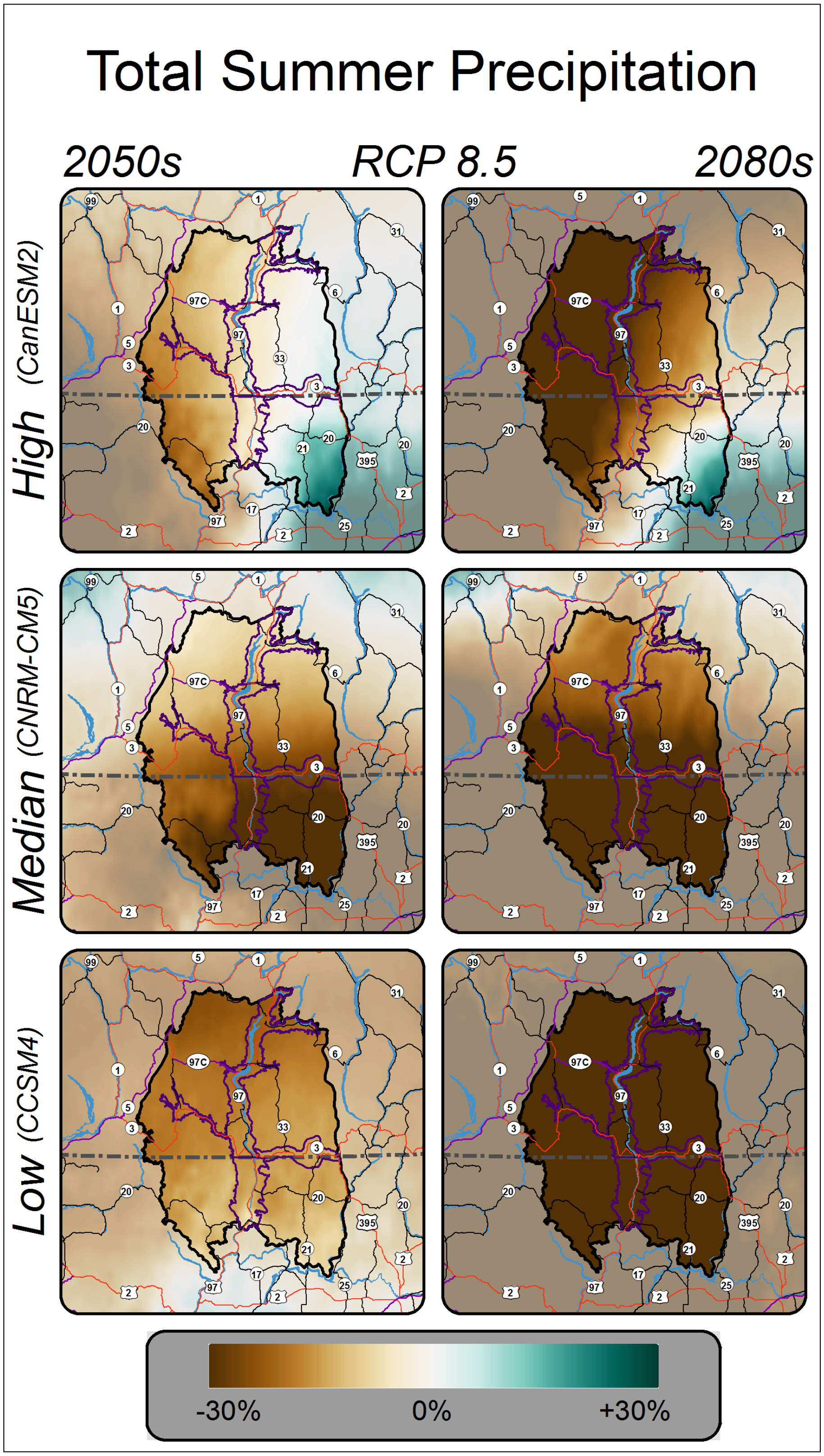
Appendix H.6e. Total Summer Precipitation, June-August

i) Extent: Okanagan Nation Territory



Appendix H.6e. Total Summer Precipitation, June-August

ii) Extent: Okanagan-Kettle Region



Appendix H.6e. Total Summer Precipitation, June-August

iii) Extent: Washington-British Columbia Transboundary Region